Michael J. McCue
Nevada Bar No. 6055
Meng Zhong
Nevada Bar No. 12145
Lewis Roca Rothgerber Christie LLP
3993 Howard Hughes Parkway, Suite 600
Las Vegas, Nevada 89169
Telephone: (702) 949-8224
E-mail: mmccue@lrrc.com
E-mail: mzhong@lrrc.com

Michael A. Dorfman (*Pro Hac Vice*)
Dykema Gossett PLLC
10 S. Wacker Dr., Suite 2300
Chicago, IL 60601
Telephone: (312) 876-1700
E-mail: mdorfman@dykema.com

Attorneys for Plaintiff Tobii AB

UNITED STATES DISTRICT COURT
DISTRICT OF NEVADA

TOBII AB, Plaintiff, v. BEIJING 7INVENSUN CO., LTD., Defendant.	**Case No. 2:18-cv-01681-MMD-BNW** **PLAINTIFF'S MOTION FOR LEAVE TO AMEND COMPLAINT PURSUANT TO FED.R.CIV.P. 15(a)(2)** **[Motion for Alternative Service and Declaration of Michael A. Dorfman filed concurrently herewith]**

Pursuant to Rule 15(a)(2) of the Federal Rules of Civil Procedure, Plaintiff Tobii AB ("Plaintiff" or "Tobii") hereby moves the Court for entry of an order granting leave for Plaintiff to file a Second Amended Complaint.

MEMORANDUM OF POINTS AND AUTHORITIES

I. LEGAL STANDARD

For a pleading not allowed as a matter of course under the Rules of Civil Procedure, a party may amend its pleadings only with the opposing party's written consent or the court's leave. Pursuant to Rule 15(a) of the Federal Rules of Civil Procedure, leave to amend shall be freely granted when justice so requires. Courts consider four factors when evaluating a plaintiff's request to amend a complaint: (1) Bad faith; (2) undue delay; (3) prejudice to the opposing party; and (4) futility of the proposed amendment. *Forman v. Davis*, 371 U.S. 178, 182 (1962);

Lockheed Martin Corp. v. Network Solutions, Inc., 194 F.3d 980, 986 (9th Cir. 1999).

II. STATEMENT OF FACTS

On September 4, 2018, Plaintiff filed the present Action against Beijing 7Invensun Co., Ltd. for patent infringement. (ECF No. 1). On January 3, 2019, Plaintiff filed its Amended Complaint. (ECF No. 11). Defendant is a Chinese company located in Wangjing, Chaoyang District, Beijing, China, with no known physical location inside the United States. (*Id.* at ¶6.)

On January 11, 2019, Plaintiff hired Sgt. Devin Smith LCO of the Laughlin Constable's Office to effectuate personal service on Defendant at the Consumer Electronics Show ("CES").

On March 29, 2019, Plaintiff filed the returned Summons. (ECF No. 14). That filing identifies that the answer was due on February 1, 2019. (*Id.*)

As discussed in Plaintiff's contemporaneously filed Motion for Alternative Service (ECF No. 16), Defendant has contested the sufficiency of service at CES in January 2019. In preparing the Motion for Alternative Service, Plaintiff noticed that Defendant's name was incorrectly identified in the caption and the body of the Amended Complaint. It is believed that Defendant's proper name is "Beijing 7Invensun Technology Co., Ltd.", not "Beijing 7Invensun Co., Ltd." (as currently identified in the caption and pleadings).

III. ARGUMENT

Tobii is not requesting amendment in bad faith. The amendment is made to include a word ("Technology") missing from the currently named defendant. In that the Defendant contends that it has not yet been properly served, no responsive pleading has been filed and no scheduling order has been entered in this case, there shall be no delay in the proceedings as a result of the amendment and no prejudice to the Defendant. Further, the amendment is not futile. The substantive allegations in the proposed Second Amended Complaint are unchanged. The amendment simply makes a correction to the name of the defendant.

IV. RELIEF REQUESTED

Tobii requests that the Court allow it to file the Second Amended Complaint attached as Exhibit A to its Motion pursuant to Fed.R.Civ.P. 15(a)(2).

///

CONCLUSION

For the foregoing reasons, the Court should enter an order granting Tobii leave to file its Second Amended Complaint.

Dated: this 3rd day of June, 2019.

LEWIS ROCA ROTHGERBER CHRISTIE LLP

By: /s/ Michael J. McCue
Michael J. McCue
Meng Zhong
3993 Howard Hughes Parkway, Suite 600
Las Vegas, NV 89169
Telephone: (702) 949-8224
E-mail: mmccue@lrrc.com
E-mail: mzhong@lrrc.com

Michael A. Dorfman (Pro Hac Vice)
Dykema Gossett PLLC
10 S. Wacker Dr., Suite 2300
Chicago, IL 60601
Telephone: (312) 876-1700
E-mail: mdorfman@dykema.com

Attorneys for Plaintiff Tobii AB

IT IS ORDERED that Plaintiff's Motion to Amend Complaint (ECF No. 17) **is GRANTED**.

IT IS FURTHER ORDERED that Plaintiff shall forthwith separately file the proposed Second Amended Complaint on the docket.

Dated: June 6, 2019

Brenda Weksler
United States Magistrate Judge

Michael J. McCue
Nevada Bar No. 6055
Meng Zhong
Nevada Bar No. 12145
Lewis Roca Rothgerber Christie LLP
3993 Howard Hughes Parkway, Suite 600
Las Vegas, Nevada 89169
Telephone: (702) 949-8224
E-mail: mmccue@lrrc.com
E-mail: mzhong@lrrc.com

Michael A. Dorfman (*Pro Hac Vice*)
Dykema Gossett PLLC
10 S. Wacker Dr., Suite 2300
Chicago, IL 60601
Telephone: (312) 876-1700
E-mail: mdorfman@dykema.com

Attorneys for Plaintiff Tobii AB

UNITED STATES DISTRICT COURT
DISTRICT OF NEVADA

TOBII AB, Plaintiff, vs. BEIJING 7INVENSUN TECHNOLOGY CO., LTD., Defendant.	**Case No.: 2:18-cv-01681-MMD-BNW** **SECOND AMENDED COMPLAINT (JURY DEMAND)**

Plaintiff, Tobii AB ("Tobii"), for its Second Amended Complaint against Defendant, Beijing 7invensun Technology Co., Ltd. ("Defendant"), states as follows:

I. JURISDICTION AND VENUE

1. This is an action that arises for patent infringement under the patent laws of the United States, 35 U.S.C. § 1, *et seq.*, including 35 U.S.C. §§ 271, 281, 283, 284 and 285. This Court has subject matter jurisdiction over this action under 28 U.S.C. §§ 1331 and 1338(a).

2. On information and belief, this Court may exercise personal jurisdiction over the Defendant based upon the Defendant's contacts with this forum, including Defendant's intentionally doing business here and having committed acts of infringement within this forum by

promoting, distributing, using, offering to sell and selling products that, when used, practice Tobii's patent including at and through participation in the annual CES show in Las Vegas, Nevada.

3. Venue is proper in this judicial district pursuant to 28 U.S.C. § 1391(c)(3). Defendant is a foreign defendant and may be sued in any judicial district. Specifically, it is a Chinese corporation with its principal place of business in Beijing, China. In *Brunette Mach. Works., Ltd. v. Kockum Indus., Inc.*, 406 U.S. 706, 706-07 (1972), the Supreme Court held that when a foreign defendant is sued in a patent infringement action, the general venue provision, 28 U.S.C. § 1391, governs.

4. The exhibits to this Amended Complaint are:

A. U.S. Patent No. 6,659,611;

B. Quick Instructions for the aGlass DK II;

C. Users' Manual for aGlass DK II;

D. Users' Manual for aGlass-vi-1;

E. Screenshots from www.aglass.com/product (visited on 16 August 2018); and

F. A claim chart applying claims 1-3 of U.S. Patent No. 6,659,611 to the aGlass DK II.

II. PARTIES

5. Tobii is a corporation organized and existing under the laws of Sweden with its principal place of business in Danderyd, Sweden. Tobii is the world leader in eye tracking and gaze interaction. Its technology makes it possible for computers to know exactly where users are looking.

6. On information and belief, Defendant is a corporation organized and existing under the laws of China with its principal place of business at Room 1801-1803, Radiance JinHui Building, Qiyang Road, Wangjing, Chaoyang District, Beijing, China. On further information and belief, Defendant has done and is doing business under the following additional name: 7invensun.

///

///

III. GENERAL ALLEGATIONS

A. The ’611 Patent

7. On December 9, 2003, the United States Patent and Trademark Office duly and legally issued U.S. Patent No. 6,659,611 (“the ’611 Patent”), entitled “System and Method for Eye Gaze Tracking Using Corneal Image Mapping,” to Arnon Amir, Myron Dale Flickner, David Bruce Koons and Carlos Hitoshi Morimoto, who assigned all of their rights and interests in the ’611 Patent to International Business Machines Corporation (“IBM”). IBM subsequently assigned all of its rights and interests in the ’611 Patent to IPG Healthcare 501 Limited, which subsequently assigned all of its rights and interests in the ’611 Patent to Tobii Technology AB. Thereafter, Tobii Technology AB changed its name to Plaintiff, Tobii AB. Thus, Tobii is the owner of the ‘611 Patent. A true and correct copy of the ’611 Patent is attached as Exhibit A to this Amended Complaint.

8. Tobii possesses all rights under the ’611 Patent and has standing to sue for past, present, and future damages, and injunctive relief.

9. Claims 1-13 of the ’611 Patent are valid and the ’611 Patent is enforceable.

B. Defendant’s Infringing Activities

10. The products manufactured, used, offered for sale, sold and imported into the United States by Defendant that infringe one or more claims of the ’611 Patent include, but are not limited to, Defendant’s eye tracking module, which, on information and belief, is called aGlass DK II. The identification of products in this Amended Complaint is by way of example only.

11. The aGlass DK II module has no substantial non-infringing use.

12. Defendant used the aGlass DK II module in the United States at the CES show in January 2018.

13. Such use of the aGlass DK II module by Defendant constitutes direct infringement of the ’611 Patent.

14. Defendant also actively encouraged CES participants to use the aGlass DK II module in the United States at the CES show in January 2018.

15. Such active encouragement by Defendant constitutes indirect infringement of the

’611 Patent.

COUNT I: PATENT INFRINGEMENT

16. Tobii re-alleges and incorporates by reference the allegations of Paragraphs 1 through 15 above as though fully set forth herein.

17. Defendant directly infringes one or more of the claims of the ’611 Patent under 35 U.S.C. §§ 271(a) by using in the United States eye tracking devices including, but not limited to, the aGlass DK II.

18. Claim 1 of the ’611 Patent reads as follows:

> 1. A method for eye gaze tracking, comprising the steps of:
>
> creating a set of reference points in a reference coordinate system;
>
> acquiring at least one image of at least one of a user’s corneas, said image having image aspects in an image coordinate system and including reflections of said reference points;
>
> defining a mathematical relationship between said reference coordinate system and said image coordinate system;
>
> mapping said image aspects from said image coordinate system to said reference coordinate system using said mathematical relationship; and
>
> computing a point of regard from said mapped image aspects.

19. Claim 2 of the ’611 Patent reads as follows:

> 2. The method of claim 1 wherein said reference points include at least one of: a printed pattern around a screen, an unobtrusively interlaced pattern in said screen, a set of controlled light sources around said screen, content displayed in said screen, a set of controlled light sources behind said screen.

20. Claim 3 of the ’611 Patent reads as follows:

> 3. The method of claim 2 wherein said screen includes at least one of: a computer monitor, a whiteboard, a desktop, a windshield, an advertisement, a television screen.

21. Pursuant to 35 U.S.C. § 271(a), Defendant has directly infringed and continues to directly infringe the ’611 Patent by using in the United States products that incorporate or make use of one or more of the inventions disclosed by the ’611 Patent, including but not limited to the aGlass DK II module. Defendant directly infringes one or more claims of the ’611 Patent,

including at least claims 1-3 of the ’611 Patent. *See* Exhibit F.

22. The aGlass DK II module performs a method for eye gaze tracking. *See* Exhibit F at row 1.

23. The aGlass DK II module creates a set of reference points in a reference coordinate system. *See* Exhibit F at row 2.

24. The aGlass DK II module acquires at least one image of at least one of a user’s corneas, said image having image aspects in an image coordinate system and including reflections of said reference points. *See* Exhibit F at row 3.

25. The aGlass DK II module defines a mathematical relationship between said reference coordinate system and said image coordinate system. *See* Exhibit F at row 4.

26. The aGlass DK II module maps said image aspects from said image coordinate system to said reference coordinate system using said mathematical relationship. *See* Exhibit F at row 5.

27. The aGlass DK II module computes a point of regard from said mapped image aspects. *See* Exhibit F at row 6.

28. The aGlass DK II module includes reference points wherein said reference points include a set of controlled light sources around said screen. *See* Exhibit F at row 7.

29. The HTC Vive, in which the aGlass DK II module is installed, includes a screen that is a computer monitor. *See* Exhibit F at row 8.

30. Unless enjoined, Defendant will continue to engage in direct infringement of the ’611 Patent and will cause additional irreparable injury to Tobii for which it has no remedy at law.

31. Pursuant to 35 U.S.C. § 271(b), Defendant has indirectly infringed and continues to indirectly infringe the ’611 Patent by actively inducing others to use in the United States the aGlass DK II module with the HTC Vive virtual reality headset.

32. Upon information and belief, with knowledge of the ’611 Patent and its infringement thereof, Defendant knowingly instructs and directs users/customers to use the aGlass DK II module in such a way as to directly infringe the ’611 Patent. For example, Defendant instructs and encourages participants at CES on proper use of the aGlass DK II module. Further,

the aGlass DK II module package includes Quick Instructions for the aGlass DK II module. *See* Exhibit B. Still further, the aGlass DK II Quick Instructions includes a QR code from which the aGlass DK II Users Manual can be downloaded. *See* Exhibit C.

33. As a direct and proximate result of Defendant's active inducement of direct infringement by third parties of the '611 Patent, Tobii has suffered injury and monetary damage for which it is entitled to recover damages.

34. Unless enjoined, Defendant will continue to actively induce infringement by third parties of the '611 Patent and will cause additional irreparable injury to Tobii for which it has no adequate remedy at law.

35. Upon information and belief, Defendant's active inducement of direct infringement by third parties has been and continues to be with full knowledge of the '611 Patent and Defendant's infringement thereof no later than the filing date of the original Complaint. Moreover, a copy of the original Complaint was sent to Defendant by e-mail on September 19, 2018.

36. Pursuant to 35 U.S.C. § 271(c), Defendant has indirectly infringed and continues to indirectly infringe the '611 Patent by contributing to the direct infringement of the '611 Patent by others in the United States through the use of the aGlass DK II module by others with the HTC Vive virtual reality headset. The aGlass DK II has no substantial non-infringing use.

37. Upon information and belief, with knowledge of the '611 Patent and its infringement thereof, Defendant knowingly instructs and directs users/customers to use the aGlass DK II module with the HTC Vive virtual reality headset in such a way as to directly infringe the '611 Patent. For example, Defendant instructs and encourages participants at CES on proper use of the aGlass DK II module with the HTC Vive virtual reality headset. Further, the aGlass DK II module package includes Quick Instructions for the aGlass DK II module. *See* Exhibit B. Still further, the aGlass DK II Quick Instructions includes a QR code from which the aGlass DK II Users Manual can be downloaded. *See* Exhibit C.

38. As a direct and proximate result of Defendant's contributory infringement of the '611 Patent, Tobii has suffered injury and monetary damage for which it is entitled to recover damages.

39. Unless enjoined, Defendant will continue to contributorily infringe the ’611 Patent and will cause additional irreparable injury to Tobii for which it has no adequate remedy at law.

40. Upon information and belief, Defendant’s contributory infringement has been and continues to be with full knowledge of the ’611 Patent and Defendant’s infringement thereof no later than the filing date of the original Complaint. Moreover, a copy of the original Complaint was sent to Defendant by e-mail on September 19, 2018.

41. Defendant’s knowing, willful and deliberate direct infringement and infringement by inducement of the ’611 Patent, including at least claim 1, in conscious disregard of Tobii’s rights, makes this case exceptional within the meaning of 35 U.S.C. § 285 and justifies treble damages pursuant to 35 U.S.C. § 284, as well as attorneys’ fees pursuant to 35 U.S.C. § 285.

PRAYER FOR RELIEF

WHEREFORE, Plaintiff Tobii prays for judgment in its favor and against Defendant as follows:

A. A permanent injunction against Defendant’s continued direct infringement of the ’611 Patent, as well as against continued inducement of infringement of this patent;

B. An award to Tobii of all damages caused by Defendant in an amount to be determined at trial;

C. A finding that Defendant’s infringement was willful entitling Tobii to an award of treble damages pursuant to 35 U.S.C. § 284;

D. A finding that Defendant’s infringement constitutes an exceptional case entitling Tobii to an award of its attorneys’ fees pursuant to 35 U.S.C. § 285;

E. An award to Tobii of pre-judgment interest at the maximum legal rate from the earliest date allowed until the date of judgment;

F. An award to Tobii of post-judgment interest at the maximum legal rate pursuant to 28 U.S.C. § 1961;

G. An award to Tobii of all costs incurred by it in connection with this lawsuit pursuant to 28 U.S.C. § 1920; and

H. Such other and further relief as the Court may deem just.

DEMAND FOR JURY TRIAL

Pursuant to Fed. R. Civ. P. 38, Tobii hereby demands a trial by jury on all issues for which a trial by jury may be had.

Dated: June 3, 2019

Lewis Roca Rothgerber Christie LLP

/s/ Michael J. McCue
Michael J. McCue (Nevada Bar No. 6055)
Meng Zhong (Nevada Bar No. 12145)
3993 Howard Hughes Parkway, Suite 600
Las Vegas, Nevada 89169
Telephone: (702) 949-8224
E-mail: MMcCue@LRRC.com
E-mail: MZhong@LRRC.com

Michael A. Dorfman (*Pro Hac Vice*)
Dykema Gossett PLLC
10 S. Wacker Dr., Suite 2300
Chicago, IL 60601
Telephone: (312) 876-1700
E-mail: mdorfman@dykema.com

Attorneys for Plaintiff Tobii AB

Exhibit A

Exhibit A

US006659611B2

(12) **United States Patent**
Amir et al.

(10) **Patent No.:** **US 6,659,611 B2**
(45) **Date of Patent:** **Dec. 9, 2003**

(54) **SYSTEM AND METHOD FOR EYE GAZE TRACKING USING CORNEAL IMAGE MAPPING**

(75) Inventors: **Arnon Amir**, Saratoga, CA (US); **Myron Dale Flickner**, San Jose, CA (US); **David Bruce Koons**, San Jose, CA (US); **Carlos Hitoshi Morimoto**, Sao Paulo (BR)

(73) Assignee: **International Business Machines Corporation**, Armonk, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 116 days.

(21) Appl. No.: **10/034,524**

(22) Filed: **Dec. 28, 2001**

(65) **Prior Publication Data**

US 2003/0123027 A1 Jul. 3, 2003

(51) **Int. Cl.**[7] **A61B 3/14**

(52) **U.S. Cl.** **351/210**

(58) **Field of Search** 351/209, 210, 351/208, 200, 205, 206, 211, 221; 382/103, 291; 708/141; 702/151

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J. Liu et al., "Three–dimensional PC: toward novel forms of human–computer interaction", in Three–Dimensional Video and Display: Devices and Systems SPIE CR76, Nov. 5–8, 2000, Boston, MA, USA.

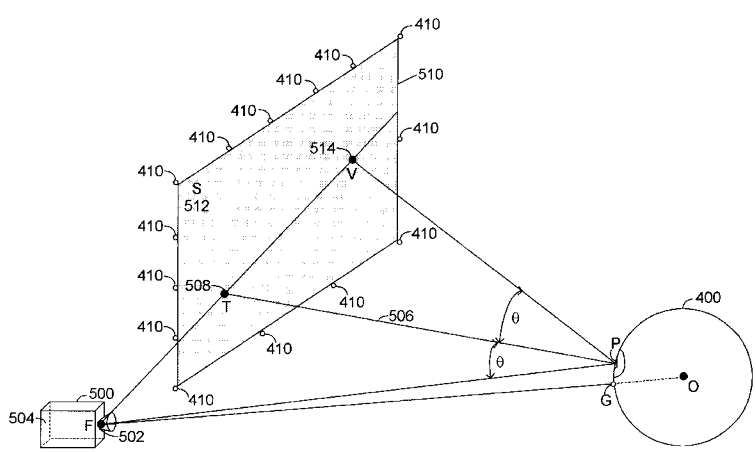
(List continued on next page.)

Primary Examiner—George Manuel
(74) *Attorney, Agent, or Firm*—Marc D. McSwain

(57) **ABSTRACT**

A system and method for eye gaze tracking without calibrated cameras, direct measurements of specific users' eye geometries, or requiring the user to visually track a cursor traversing a known trajectory. The preferred embodiment includes two uncalibrated cameras imaging the user's eye and haying on-axis lighting. The cameras capture images of a test pattern in real space as reflected from the user's cornea, which is essentially a convex spherical mirror. The invention then extracts parameters required to define a mathematical mapping between real space and image space, including spherical and perspective transformations. The invention processes subsequent images of objects reflected from the user's eye through the inverse of the mathematical mapping to determine a gaze vector and a point of regard. Alternately, a single calibrated camera may be employed with means for estimating the eye-to-camera distance. A head-mounted embodiment that may include a laser pointer is also described.

15 Claims, 7 Drawing Sheets



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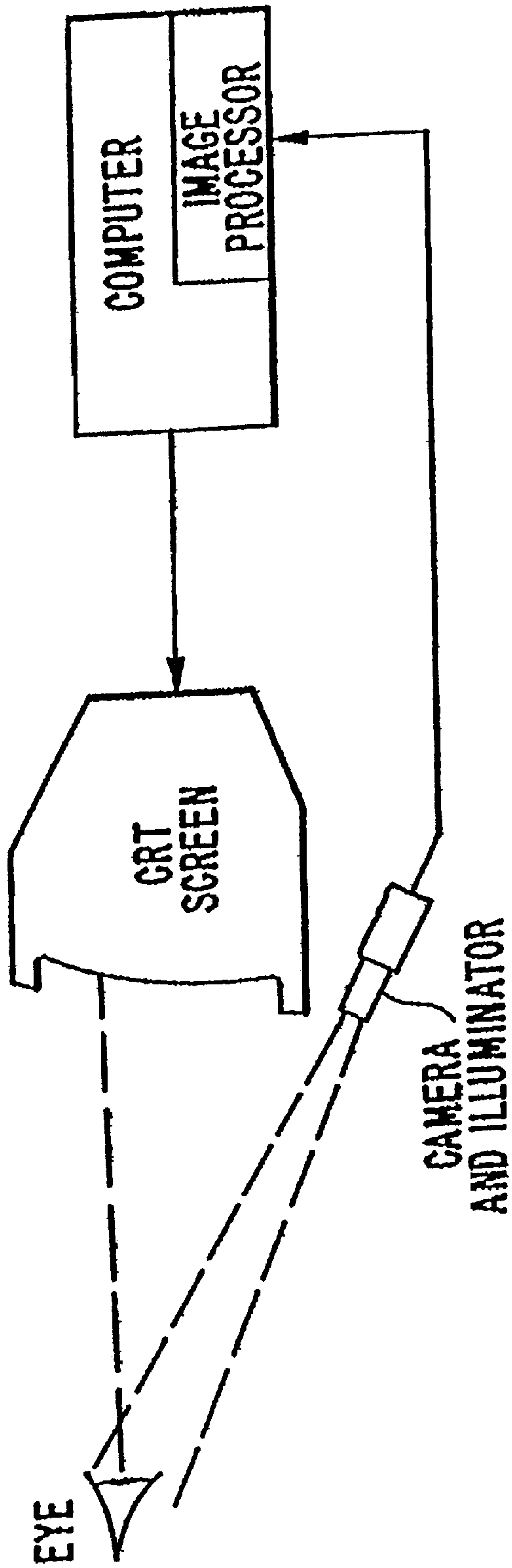


FIG. 1 (PRIOR ART)

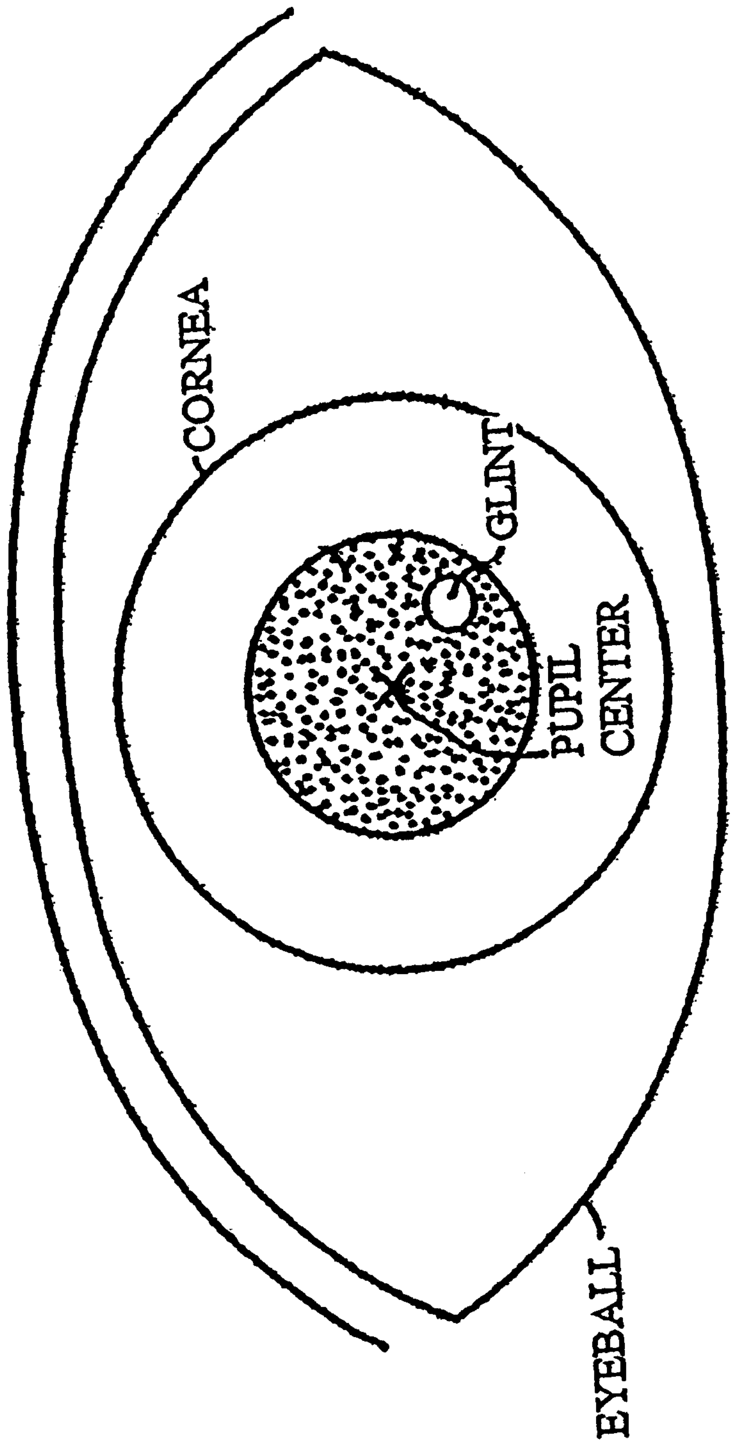


FIG. 2 (PRIOR ART)

FIG. 3 (PRIOR ART)

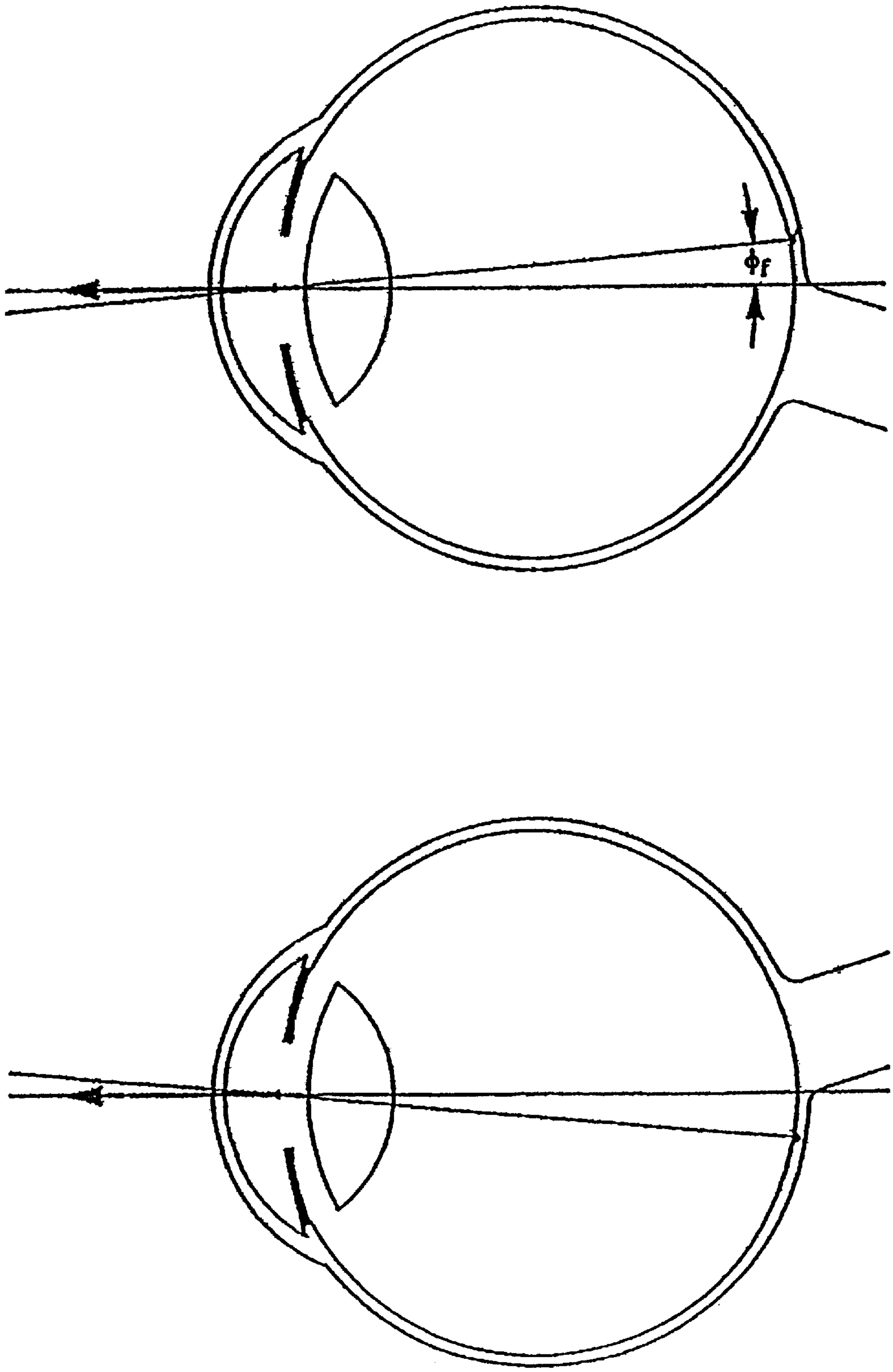
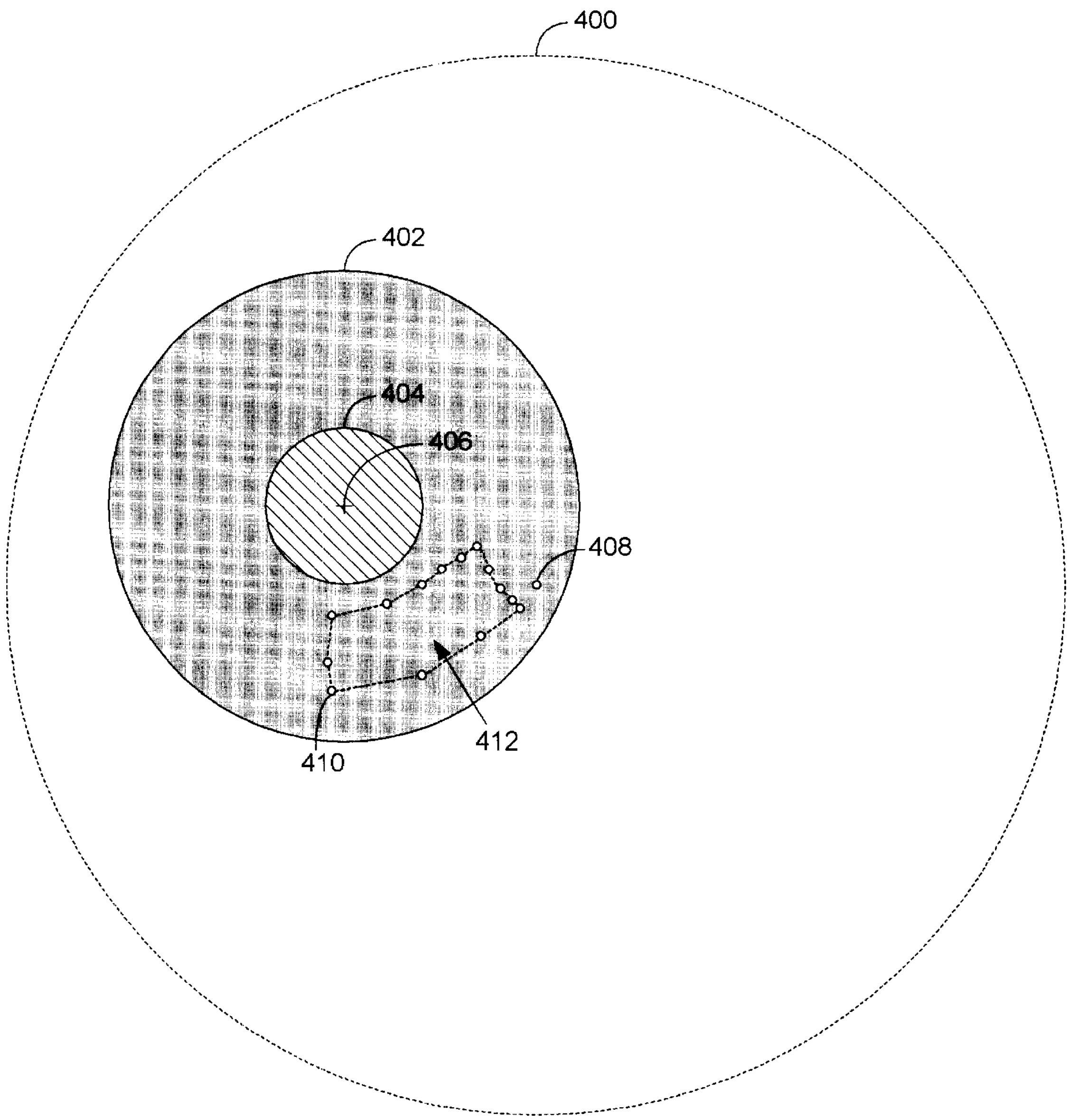


FIG. 4



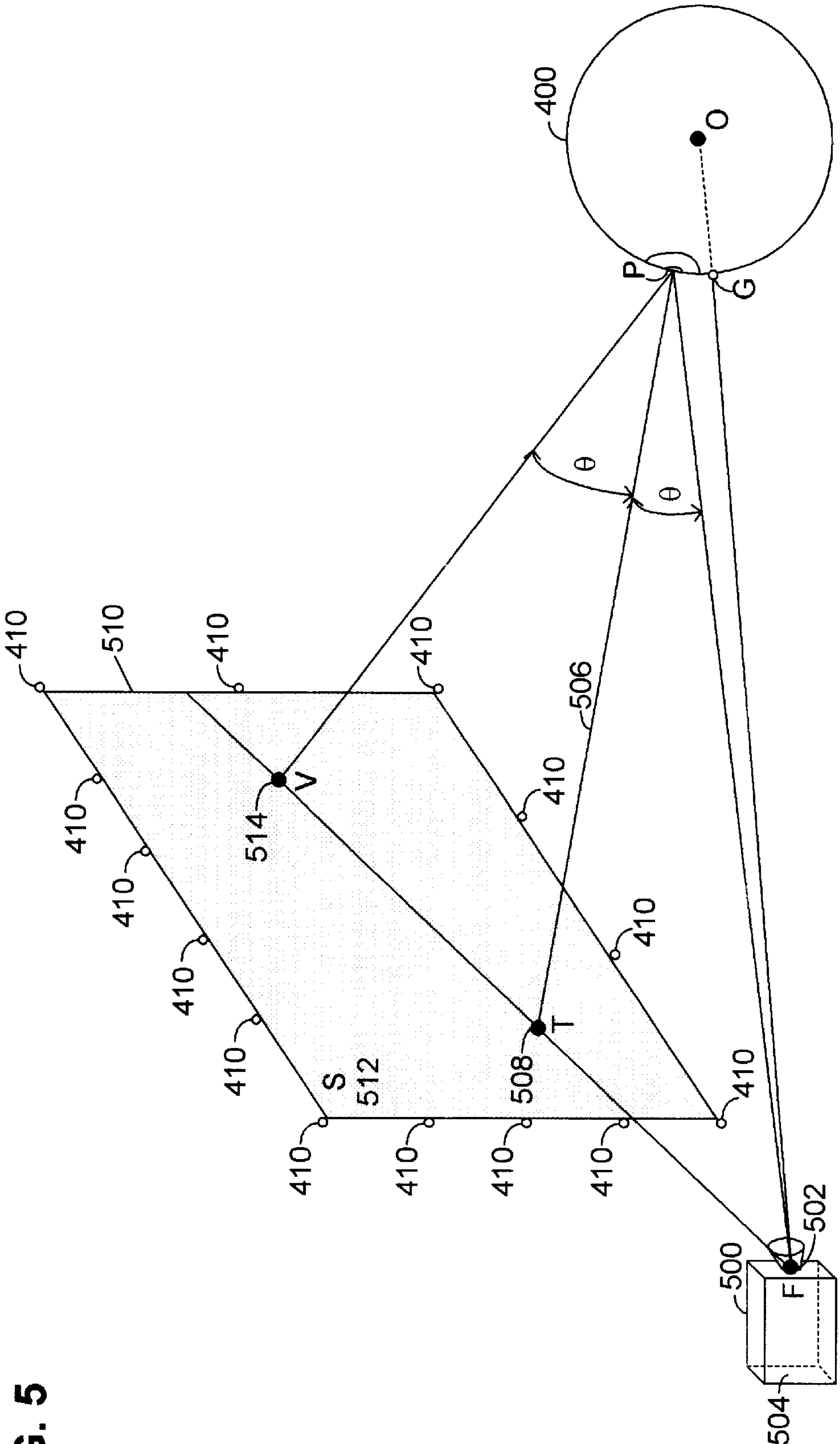


FIG. 5

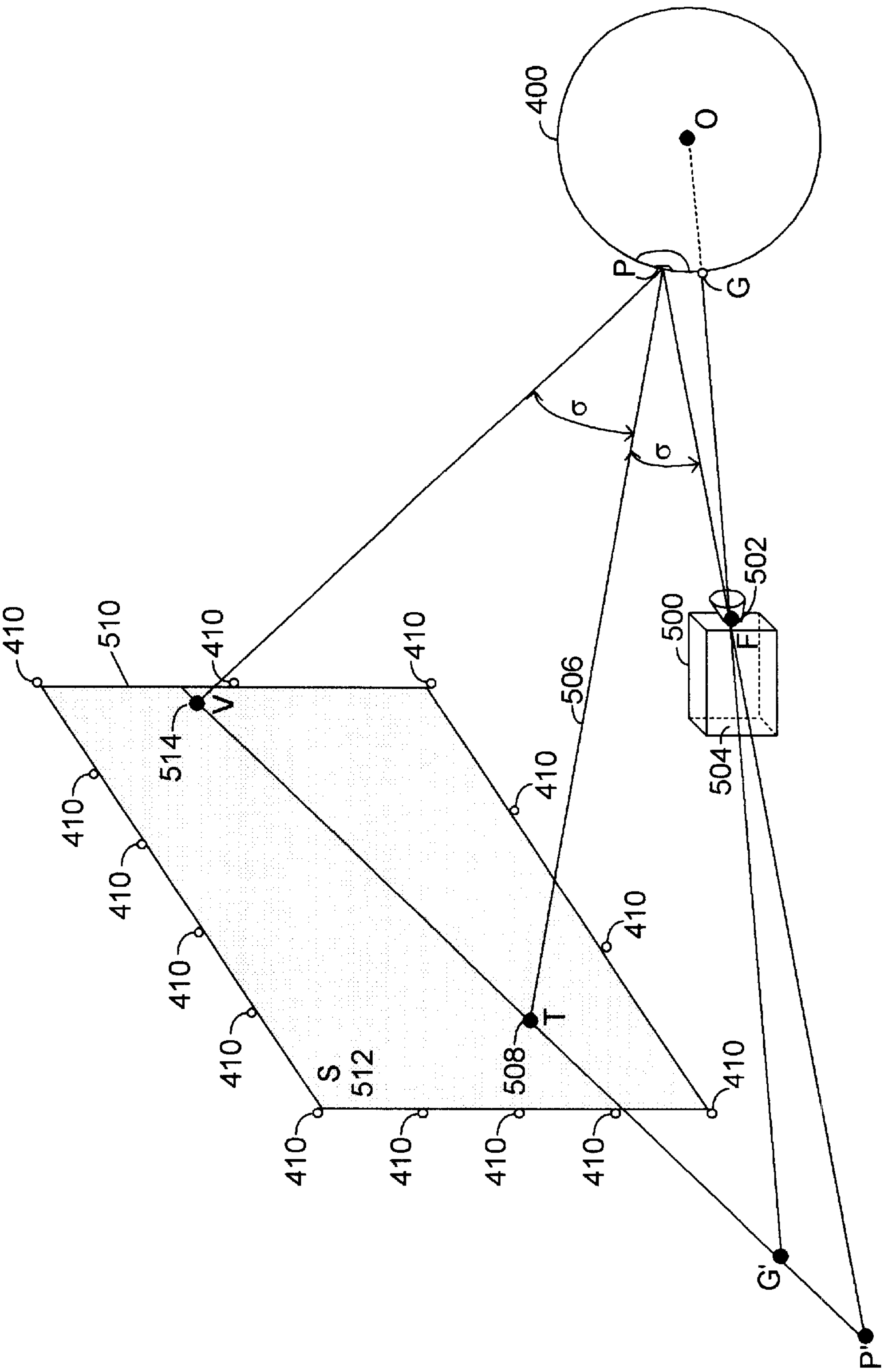
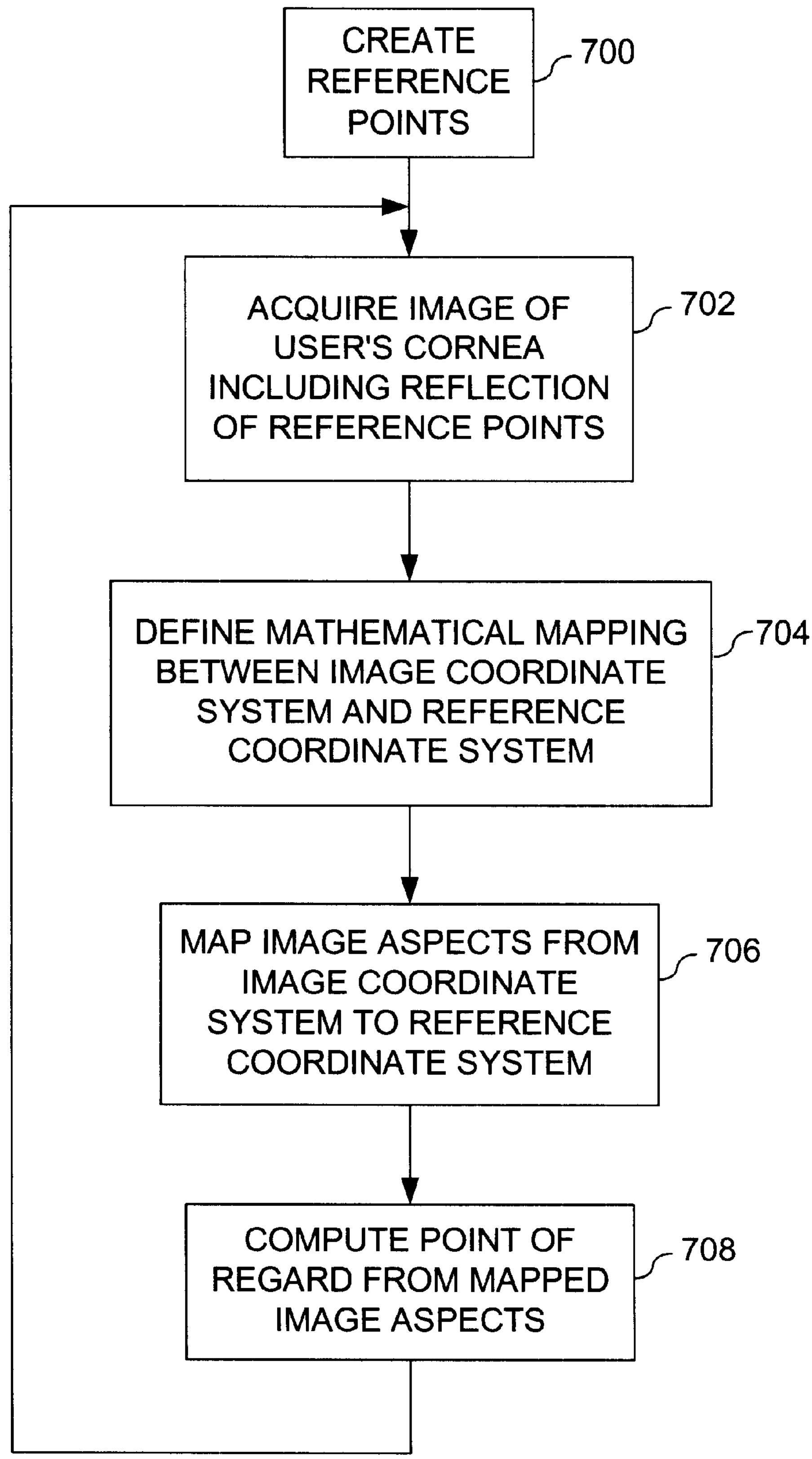


FIG. 6

FIG. 7


CREATE REFERENCE POINTS
700
ACQUIRE IMAGE OF USER'S CORNEA INCLUDING REFLECTION OF REFERENCE POINTS
702
DEFINE MATHEMATICAL MAPPING BETWEEN IMAGE COORDINATE SYSTEM AND REFERENCE COORDINATE SYSTEM
704
MAP IMAGE ASPECTS FROM IMAGE COORDINATE SYSTEM TO REFERENCE COORDINATE SYSTEM
706
COMPUTE POINT OF REGARD FROM MAPPED IMAGE ASPECTS
708

SYSTEM AND METHOD FOR EYE GAZE TRACKING USING CORNEAL IMAGE MAPPING

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is related to U.S. Ser. No. 09/844,682 "Calibration-Free Eye Gaze Tracking", a commonly-owned patent application filed on Apr. 27, 2001, which is hereby incorporated by reference. This patent application is also related to U.S. Ser. No. 09/238,979 "Method and Apparatus for Associating Pupils with Subjects", a commonly-owned patent application filed on Jan. 27, 1999, which is hereby incorporated by reference.

FIELD OF THE INVENTION

This invention relates to eye gaze tracking by analysis of images taken of a user's eye. The invention relates more specifically to eye gaze tracking without calibrated cameras, direct measurements of specific users' eye geometries, or requiring the user to visually track a cursor traversing a known trajectory.

BACKGROUND OF THE INVENTION

Eye gaze tracking technology has proven to be useful in many different fields, including human-computer interfaces for assisting disabled people interact with a computer. The eye gaze tracker can be used as an input device, instead of or in addition to a mouse for a personal computer, for example, helping disabled people to move a cursor on a display screen to control their environment and communicate messages. Gaze tracking can also be used for industrial control, aviation, and emergency room situations where both hands are needed for tasks other than operation of a computer but where an available computer is useful. There is also significant research interest in eye gaze tracking for babies and animals to better understand such subjects' behavior and visual processes.

There are many different schemes for detecting both the gaze direction and the point of regard, and many vendors of eye gaze tracking equipment (see for example web site http://ibs.derby.ac.uk/emed). Any particular eye gaze tracking technology should be relatively inexpensive, reliable, unobtrusive, easily learned and used and generally operator-friendly to be widely accepted. However, commercially available systems are expensive (over $10,000), complicated to install, and require a trained operator and a calibration process before each use session.

Corneal reflection eye gaze tracking systems project light toward the eye and monitor the angular difference between pupil position and the reflection of the light beam from the cornea surface. Near-infrared light is often employed, as users cannot see this light and are therefore not distracted by it. The light reflected from the eye has two major components. The first component is a 'glint', which is a very small and very bright virtual image of the light source reflected from the front surface of the corneal bulge of the eye; the glint is also known as the first Purkinje image. The second component is light that has entered the eye and has been reflected back out from the retina. This light serves to illuminate the pupil of the eye from behind, causing the pupil to appear as a bright disk against a darker background. This retroreflection, or "bright eye" effect familiar to flash photographers, provides a very high contrast image. An eye gaze tracking system determines the center of the pupil and

the glint, and the change in the distance and direction between the two as the eye is rotated. The orientation of the eyeball can be inferred from the differential motion of the pupil center relative to the glint. The eye is often modeled as a sphere of about 12.3 mm radius having a spherical corneal bulge of about 7.4 mm radius (see "Schematic Eye" by Gullstrand, in *Visual Optics*, H. H. Emsley editor, 3^{rd} ed., p. 348, Butterworth, Scarborough, Ont., 1955, which is hereby incorporated by reference). The eyes of different users will have variations from these typical values, but individual dimensional values do not generally vary significantly in the short term, and thus can be stored and used for a long period.

As shown in prior art FIG. **1**, the main components of a corneal reflection eye gaze tracking system include a video camera sensitive to near-infrared light, a near-infrared light source (often a light-emitting diode) typically mounted to shine along the optical axis of the camera, and a computer system for analyzing images captured by the camera. The on-axis light source is positioned at or near the focal center of the camera. Image processing techniques such as intensity thresholding and edge detection identify the glint and the pupil from the image captured by the camera using on-axis light, and locate the pupil center in the camera's field of view as shown in prior art FIG. **2**.

Human eyes do not have uniform resolution over the entire field of view, nor is the portion of the retina providing the most distinct vision located precisely on the optical axis. The eye directs its gaze with great accuracy because the photoreceptors of the human retina are not uniformly distributed but instead show a pronounced density peak in a small region known as the fovea centralis. In this region, which subtends a visual angle of about one degree, the receptor density increases to about ten times the average density. The nervous system thus attempts to keep the image of the region of current interest centered accurately on the fovea as this gives the highest visual acuity. A distinction is made between the optical axis of the user's eye versus the foveal axis along which the most acute vision is achieved. As shown in prior art FIG. **3**, the optical axis is a line going from the center of the spherical corneal bulge through the center of the pupil. The optical axis and foveal axis are offset in each eye by an inward horizontal angle of about five degrees, with a variation of about one and one half degrees in the population. The offsets of the foveal axes with respect to the optical axes of a user's eyes enable better stereoscopic vision of nearby objects. The offsets vary from one individual to the next, but individual offsets do not vary significantly in the short term. For this application, the gaze vector is defined as the optical axis of the eye. The gaze position or point of regard is defined as the intersection point of the gaze vector with the object being viewed (e.g. a point on a display screen some distance from the eye). Adjustments for the foveal axis offsets are typically made after determination of the gaze vector; a default offset angle value may be used unless values from a one-time measurement of a particular user's offset angles are available.

Unfortunately, calibration is required for all existing eye gaze tracking systems to establish the parameters describing the mapping of camera image coordinates to display screen coordinates. Different calibration and gaze direction calculation methods may be categorized by the actual physical measures they require. Some systems use physically-based explicit models that take into account eyeball radius, radius of curvature of the cornea, offset angle between the optical axis and the foveal axis, head and eye position in space, and distance between the center of the eyeball and the center of the pupil as measured for a particular user. Cameras may

need to be calibrated as well, so that their precise positions and optical properties are known. Details of camera calibration are described in "A Flexible New Technique for Camera Calibration", Z. Zhang, IEEE Transactions on Pattern Analysis and Machine Intelligence, 22(11):1330–1334, 2000, (also available as Technical Report MSR-TR-98-71 at http://research.microsoft.com/~zhang/Papers/TR98-71.pdf), hereby incorporated by reference.

During system calibration, the user may be asked to fix his or her gaze upon certain "known" points in a display. At each coordinate location, a sample of corresponding gaze vectors is computed and used to accommodate head position, screen position and size, camera position, and to adapt the system to the specific properties of the user's eye, reducing the error in the estimate of the gaze vector to an acceptable level for subsequent operation. This method is disadvantageous in that a user's flow of thought is interrupted because the gaze target has nothing to do with the work the user wishes to perform. Further, the user may also be asked to click a mouse button after visually fixating on a target, but this approach may add synchronization problems, i.e. the user could look away from the target and then click the mouse button. Also, with this approach the system would get only one mouse click for each target, so there would be no chance to average out involuntary eye movements. System calibration may need to be performed on a per-user or per-tracking-session basis, depending on the precision and repeatability of the tracking system. A major disadvantage of the calibration process is that it requires the user's cooperation, and thus is unsuitable for infants, animals and for non-cooperative subjects.

U.S. Pat. No. 6,152,563 to Hutchinson et al. describes a typical corneal reflection eye gaze tracking system. The user looks at a sequence of fixed points on the screen to enable the system to map a particular glint-pupil displacement to a particular point on the screen. U.S. Pat. No. 5,231,674 to Cleveland et al. teaches another corneal reflection eye gaze tracking system.

U.S. Pat. No. 5,325,133 to Adachi teaches a method for eye gaze tracking in which the relative brightness of the pupil image as observed from multiple displacement angles determines a gaze vector. Alternate light source activation, or use of light sources of different wavelengths, correlates particular light sources with particular pupil images or pupil brightness measurements.

European Patent Application EP0631222A1, incorporated herein by reference, teaches a method of calculating the center position of a pupil image wherein the brightness of a gazing point on a display is increased, causing a change in pupil area subsequently used to verify the pupil image center position. This application also teaches the use of a simple linear relationship between screen coordinates (u,v) and pupil image center coordinates (x,y), u=ax+b and v=cy+d, where parameters (a, b, c and d) are determined when pupil center position data is obtained at two locations.

U.S. Pat. No. 5,481,622 to Gerhardt et al. teaches a head-mounted eye-tracking system that constructs a mapping relationship between the relative position of the pupil image center position and the point of regard on a display screen. The user gazes at a cursor placed at a known position in a display screen, and the invention determines the pupil center position in image coordinates. This process is repeated many times, and a set of polynomial functions are eventually fitted to define the mapping relationship.

U.S. Pat. Nos. 5,231,674, 5,325,133, 5,481,622, 6,152,563 are all incorporated herein by reference.

While the aforementioned prior art methods are useful advances in the field of eye gaze tracking, systems that do not require user-apparent calibration would increase user convenience and broaden the acceptance of eye gaze tracking technology. A system for eye gaze tracking without calibrated cameras, direct measurements of specific users' eye geometries, or requiring the user to visually track a cursor traversing a known trajectory is therefore needed.

SUMMARY OF THE INVENTION

It is accordingly an object of this invention to devise a system and method for eye gaze tracking wherein calibrated cameras and direct measurement of individual users' eye geometries are not required.

It is a related object of the invention to devise a system and method for eye gaze tracking wherein the user is not required to fixate on a series of visual targets located at known positions, or to visually track a cursor traversing a known trajectory.

It is a related object of the invention to determine a gaze vector and to compute a point of regard, which is the intersection of the gaze vector and an observed object. The observed object is preferably a display screen or computer monitor, but may also include a desktop, a windshield, a whiteboard, an advertisement, a television screen, or any other object over which a user's vision may roam.

It is a related object of the preferred embodiment of the invention that two cameras are used to capture images of a user's eye, where each camera includes an on-axis light source, a focal center, and an image plane defining an image coordinate system. It is a related object of the preferred embodiment of the invention to capture images of a user's eye such that the pupil center in each image and a glint resulting from the particular camera's light source may be readily identified and located in the image plane of each camera.

It is a related object of the preferred embodiment of the invention that the cameras capture images of a set of reference points, or a test pattern, that defines a reference coordinate system in real space. The images include reflections of the test pattern from the user's cornea, which is essentially a convex spherical mirror. The invention maps or mathematically relates the test pattern image in the camera image coordinate systems to the actual test pattern through spherical and perspective transformations. The parameters of the relation may include the eye-to-camera distance, the vertical and horizontal displacement of the eye from the test pattern, and the radius of cornea curvature.

The test pattern may comprise an unobtrusively interlaced pattern depicted in a display screen, a set of light sources around a display screen border that may be sequentially activated, a printed pattern around the display screen, a set of light sources placed on the display screen surface, or any other distinctive pattern not attached to the display screen but within the user's view of the display screen vicinity. The test pattern is preferably invisible or not obtrusive to the user. The test pattern is preferably coplanar with the surface the user is viewing, but is not constrained as such, i.e. there may be separate reference and target coordinate systems sharing a known mapping relationship. The cameras are preferably positioned in the plane of the test pattern, and may for example be built into a computer display screen. Cameras may be attached to a head mounted device, such as a helmet or glasses. Alternately, the cameras may be positioned away from the reference plane and the plane of the user-viewed surface.

Once the invention defines the mapping between the reference coordinate system and the image coordinate system, the invention applies the mapping to subsequent images reflected from the user's cornea. The glint from the on-axis light source, the focal center of the camera, and the pupil center define a plane in real space that intersects with a user-viewed planar surface along a line. This line contains the point of regard T, which lies between the glint and the pupil center as mapped onto the screen coordinate system. The line also contains point V, where a virtual light source would produce a glint at the pupil center of the reflected corneal image as seen by the camera. The gaze vector is the bisector of the angle between the focal center of the camera, the pupil center in real space, and point V.

The invention uses the mapping relationship already determined via the test pattern to compute where a virtual light source would have to be on the user-viewed surface to create a reference point in the pupil center in the camera image coordinate system. If uncalibrated cameras are used, two cameras are required to uniquely determine the point of regard T. If one calibrated camera is used, the distance from the camera's focal center to the user's pupil needs to be known or estimated; the focal length of the camera and an estimate of the distance between the user's eyes can be used to estimate eye-to-camera distance.

The invention may also interpolate the location of points T or V from a test pattern around the perimeter of the display screen, including the mapping described above. At least one of the cameras may be head-mounted. A laser pointer can generate additional reference points, and can be actively aimed to establish a reference point at point V for example. Correction for foveal axis offsets may be added.

The foregoing objects are believed to be satisfied by the embodiments of the present invention as described below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a prior art diagram of an eye gaze tracking system.

FIG. **2** is a prior art diagram of a user's eye as viewed by a camera.

FIG. **3** is a prior art diagram of the foveal and optical axes and their offset angle.

FIG. **4** is a diagram of the user's eye according to the preferred embodiment of the present invention.

FIG. **5** is a diagram of the user's eye with regard to a camera located in a screen plane according to the preferred embodiment of the present invention.

FIG. **6** is a diagram of the user's eye with regard to a camera located out of the screen plane according to the preferred embodiment of the present invention.

FIG. **7** is a flowchart of the eye gaze tracking method according to the preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. **4**, a diagram of user's eye **400** according to the preferred embodiment of the present invention is shown. The user's eye **400** includes the eyeball or sclera, a substantially spherical cornea **402**, and a pupil **404** having a pupil center **406**. Note that non-spherical cornea models, including parabolic models, are known in the art and can also be employed by the present invention. At least one camera (not shown) captures images of user's eye **400**, particularly cornea **402**. FIG. **4** is such an image. Cameras may be head-mounted for easy acquisition of an eye image, but are preferably not head-mounted so the invention will be more widely accepted by users. The cameras track the user's head motion using known techniques. Each camera includes a focal center, an on-axis light source illuminating the eye, and an image plane defining an image coordinate system. The light source is preferably invisible to prevent user distraction, and may for example emit radiation in the near-infrared wavelength range. The images of user's eye **400** include image aspects that will be used for determination of an eye gaze vector and determination of a point of regard, which is the intersection of the gaze vector and an observed object. These image aspects include a glint **408** due to light from the on-axis light source reflecting from eye **400** (either sclera or cornea **402**) directly back to the camera. (pupil center **406** may be offset slightly due to refraction through cornea **402**; the offset can be computed by the present invention, using an estimate of the index of refraction and the distance of pupil **404** behind cornea **402** according to the Gullstrand eye model.) The image aspects also include a pupil image preferably created via retroreflection as is known in the art. Various image processing methods for identifying and locating the center of glint **408**, pupil **404**, and pupil center **406** in captured images of user's eye **400** are known in the art.

The image aspects also include a reflected version of a set of reference points **410** forming a test pattern **412**. Reference points **410** define a reference coordinate system in real space. The relative positions of reference points **410** to each other are known, and reference points **410** are preferably co-planar, although that is not a limitation of the present invention. The reflection of reference points **410** is spherically distorted by reflection from cornea **402**, which serves essentially as a convex spherical mirror. The reflected version of reference points **410** is also distorted by perspective, as eye **400** is some distance from the camera and the reflected version goes through a perspective projection to the image plane. That is, test pattern **412** will be smaller in the image plane when eye **400** is farther away from reference points **410**. The reflection also varies in appearance due to the radius of cornea curvature, and the vertical and horizontal translation of user's eye **400**.

There are many possible ways of defining the set of reference points **410** or test pattern **412**. Test pattern **412** is preferably generated by a set of point light sources deployed around a display screen perimeter. If necessary, the light sources can be sequentially activated to enable easier identification of which light source corresponds to which image aspect. For example, a set of lights along one vertical edge of the display screen may be activated during acquisition of one image, then a set of lights along one horizontal edge of the display screen, and so forth. A variety of different lighting sequences and patterns can be used. The light sources can be built into a computer monitor during manufacture or subsequently attached to the screen, and preferably emit infrared light. Alternately, test pattern **412** may comprise an unobtrusively interlaced design depicted in a display screen; in this case no separate light sources are needed, but the camera is preferably synchronized to acquire an image of test pattern **412** reflection when the design is being displayed. A set of light sources on the display screen itself can also generate test pattern **412**; for example, pixels in a liquid crystal display may include an infrared-emitting device such as a light-emitting diode. It is known in the art that red liquid crystal display cells are at least partially transparent to infrared light. Another method for defining test pattern **412** is to deploy a high-contrast pre-printed

pattern around the display screen perimeter; a checkerboard pattern for example.

In yet another variation, the regularly depicted display screen content can itself serve as test pattern **412**. The content can be fetched from video memory or a display adapter (not shown) to allow matching between the displayed content and image aspects. If a high frame rate camera is used, camera frames may be taken at a different frequency (e.g. twice the frequency) than the display screen refresh frequency, thus frames are captured in which the screen reflection changes over time. This allows easier separation of the screen reflection from the pupil image, e.g. by mere subtraction of consecutive frames. Generally, any distinctive pattern within the user's view can comprise test pattern **412**, even if not attached to the display screen or other object being viewed.

In the examples above, test pattern **412** is usually co-planar with the surface being viewed by the user, such as a computer monitor or display screen, but the present invention is not constrained as such. The reference coordinate system may not necessarily coincide with a coordinate system describing the target on which a point of regard exists, such as the x-y coordinates of a computer monitor. As long as a mapping between the reference coordinate system and the target coordinate system exists, the present invention can compute the point of regard. Other target objects could include but are not limited to a desktop, a whiteboard, and a windshield. The camera is preferably positioned in the plane of reference points **410**, but the present invention is not limited to this embodiment, as will be described below.

The present invention mathematically maps the reference coordinate system to the image coordinate system by determining the specific spherical and perspective transformations that cause reference points **410** to appear at specific relative positions in the reflected version of test pattern **412**. The invention updates the mathematical mapping as needed to correct for changes in the position or orientation of user's eye **400**, but this updating is not necessarily required during every cycle of image capture and processing. The invention then applies the mathematical mapping to image aspects other than reflected reference points **410**, such as glint **408** and pupil center **406**, as will be described below.

Referring now to FIG. **5**, a diagram of user's eye **400** with regard to a camera located in a screen plane according to the preferred embodiment of the present invention is shown. Camera **500** includes a focal center **502**, an image plane **504** that defines an image coordinate system, and an on-axis light source (not shown). The center of user's eye **400** is designated as point O. The reflection point of the on-axis light source from user's eye **400** is designated as point G, which is seen by camera **500** as glint **408** as shown in FIG. **4**. The center of the pupil is designated as point P in real space, and is seen by camera **500** as pupil center **406** in image coordinates. Gaze vector **506** is the line extending from point P to the specific location (point T) on an object being directly observed by a user. Point of regard **508** is thus the intersection of gaze vector **506** with an observed object, and in this description the observed object is a display screen **510** as typically employed with a computer. Display screen **510** is preferably modeled as plane S, which is screen plane **512**. While the observed object is preferably planar, the invention is not limited to gaze tracking on planar objects, as will be described further below. Point V is the position of a virtual light source **514** that, if it actually existed at point V, its reflection from user's eye **400** would appear to coincide with pupil center **406** in image plane **504** of camera **500**. Or, going the other way, point V is the location of the pupil center **406** when mapped from image coordinates to screen plane coordinates. Points F, P, G, O, T, and V as shown in FIG. **5** are all co-planar. Points F, T, and V lie on a line that is co-planar with screen plane S. Angle FPT and angle VPT are equal; in other words, gaze vector **506** bisects angle FPV.

The preferred embodiment of the invention employs at least one camera **500** co-planar with screen plane **512** to capture an image of reference points as reflected from cornea **402**. Specific reference points may be identified by many different means, including alternate timing of light source energization as well as matching of specific reference point distribution patterns. The invention then determines the specific spherical and perspective transformations required to best map the reference points in real space to the test pattern they form in image space. The invention can for example optimize mapping variables (listed above) to minimize the difference between the observed test pattern in image coordinates and the results of transforming a known set of reference points in real space into an expected test pattern in image coordinates. Once the mathematical mapping between the image coordinate system and the reference coordinate system is defined, the invention applies the mapping to observed image aspects, such as backlighted pupil images and the glint due to the on-axis light source. The invention can compute the location of point V in the coordinates of the observed object (screen plane **512**) by locating pupil center **406** in image coordinates and then mathematically converting that location to coordinates within screen plane **512**. Similarly, the invention can compute the location of glint **408** in image coordinates and determine a corresponding location in the coordinates of the observed object; in the case where camera **500** is co-planar with screen plane **512**, the mapped glint point is simply focal center **502**. Point of regard **508** on screen plane **512** is typically the bisector of a line segment between point V and such a mapped glint point. Glint **408** and pupil center **406** can be connected by a line in image coordinates and then reference point images that lie near the line can be selected for interpolation and mapping into the coordinates of the observed object.

A single calibrated camera **500** can determine point V and bisection of angle FPV determines gaze vector **506**; if the eye-to-camera distance FP is known then the intersection of gaze vector **506** with screen plane **512** can be computed and determines point of regard **508**. The eye-to-camera distance can be measured or estimated in many different ways, including the distance setting at which camera **500** yields a focused image, the scale of an object in image plane **504** as seen by a lens of known focal length, or via use of an infrared rangefinder.

The present invention can also employ uncalibrated cameras **500** for gaze tracking, which is a significant advantage over existing gaze tracking systems. Each uncalibrated camera **500** can determine a line on screen plane **512** containing point of regard **508**, and the intersection of two such lines determines point of regard **508**. Mere determination of a line that contains point of regard **508** is of use in many situations, as described in U.S. Ser. No. 09/844,682 cited previously.

When non-planar objects are being viewed, the intersection of the object with plane FPV is generally a curve instead of a line, and the method of computing gaze vector **506** by bisection of angle FPV will yield only approximate results. However, these results are still useful if the object being observed is not too strongly curved, or if the curvature is included in the mathematical mapping.

An alternate embodiment of the present invention employs a laser pointer to create at least one reference point.

The laser pointer can be scanned to produce a test pattern on objects in real space, so that reference points need not be placed on observed objects a priori. Alternately, the laser pointer can be actively aimed, so that the laser pointer puts a spot at point V described above (i.e. a reflection of the laser spot is positioned at pupil center **406** in the image coordinate system). The laser may emit infrared or visible light.

Gaze vector **506**, however determined, can control a laser pointer such that a laser spot appears at point of regard **508**. As the user observes different objects and point of regard **508** changes, the laser pointer follows the motion of the point of regard so that user eye motion can be observed directly in real space.

Referring now to FIG. **6**, a diagram of user's eye **400** with regard to a camera **500** located out of the screen plane according to the preferred embodiment of the present invention is shown. Although focal center **502** is no longer co-planar with screen plane **512**, the images of glint **408** and pupil center **406** can be effectively projected back mathematically as points P' and G' on a line that is co-planar with screen plane **512**. Point T is on the line connecting point G' with point V, as previously described.

Referring now to FIG. **7**, a flowchart of the eye gaze tracking method according to the preferred embodiment of the present invention is shown. In step **700**, reference points **410** as described above are created or activated. Next, in step **702** the invention acquires at least one image of cornea **402** including reflections of reference points **410**. In step **704**, the invention defines a mathematical mapping between the image coordinate system and the reference coordinate system by determining the transformations (e.g. spherical and perspective) that cause reference points **410** as distributed in the image coordinate system to best fit their expected positions based on their known distribution in the reference coordinate system. The invention then maps image aspects such as glint **408** and pupil center **406** from the image coordinate system to the reference coordinate system in step **706**. Finally, the invention computes the point of regard from the mapped image aspects in step **708**, and returns to step **702** to repeat the eye gaze tracking method steps described. Note that steps **702** and **704** need not necessarily be performed during every single execution cycle of the method; it is within the scope of the invention that the mapping of coordinate systems by analysis of reflected reference points **410** may be performed only occasionally so the invention spends most of its time mapping image aspects other than reference points **410** and tracking the point of regard as described in steps **706** and **708**.

A general purpose computer is programmed according to the inventive steps herein. The invention can also be embodied as an article of manufacture—a machine component—that is used by a digital processing apparatus to execute the present logic. This invention is realized in a critical machine component that causes a digital processing apparatus to perform the inventive method steps herein. The invention may be embodied by a computer program that is executed by a processor within a computer as a series of computer-executable instructions. These instructions may reside, for example, in RAM of a computer or on a hard drive or optical drive of the computer, or the instructions may be stored on a DASD array, magnetic tape, electronic readonly memory, or other appropriate data storage device.

While the invention has been described with respect to illustrative embodiments thereof, it will be understood that various changes may be made in the apparatus and means herein described without departing from the scope and teaching of the invention. Accordingly, the described embodiment is to be considered merely exemplary and the invention is not to be limited except as specified in the attached claims.

We claim:

1. A method for eye gaze tracking, comprising the steps of:

creating a set of reference points in a reference coordinate system;

acquiring at least one image of at least one of a user's corneas, said image having image aspects in an image coordinate system and including reflections of said reference points;

defining a mathematical relationship between said reference coordinate system and said image coordinate system;

mapping said image aspects from said image coordinate system to said reference coordinate system using said mathematical relationship; and

computing a point of regard from said mapped image aspects.

2. The method of claim **1** wherein said reference points include at least one of: a printed pattern around a screen, an unobtrusively interlaced pattern in said screen, a set of controlled light sources around said screen, a set of controlled light sources on said screen, content displayed in said screen, a set of controlled light sources behind said screen.

3. The method of claim **2** wherein said screen includes at least one of: a computer monitor, a whiteboard, a desktop, a windshield, an advertisement, a television screen.

4. The method of claim **1** wherein a laser pointer creates at least one new reference point.

5. The method of claim **4** wherein said laser pointer creates said new reference point that reflects from said cornea at a pupil image center in said image coordinate system.

6. The method of claim **1** wherein said acquiring step is performed by at least one camera focusing upon at least one of said user's corneas, each said camera having a focal center, an image plane defining said image coordinate system, and an on-axis light source.

7. The method of claim **6** wherein said image aspects are identified by subtracting a number of said images acquired during different phases of display screen refresh cycles.

8. The method of claim **6** comprising the further steps of:

determining for each of said cameras an angle between said focal center, a user's pupil center, and a point on a predetermined target surface where a virtual light source would create a new image aspect at a pupil image center in said image coordinate system; and

defining a gaze vector as the bisector of said angle.

9. The method of claim **8** comprising the further step of correcting said gaze vector for a foveal axis offset angle.

10. The method of claim **6** wherein at least one of said cameras is head-mounted.

11. The method of claim **1** wherein said mathematical relationship includes at least one of: spherical transformations, perspective transformations, polynomial interpolation.

12. The method of claim **1** wherein said computing step includes the further steps of:

mapping a target coordinate system to said reference coordinate system; and

bisecting a line segment spanning an on-axis glint and a pupil image center in said target coordinate system.

13. The method of claim **12** wherein said target coordinate system is said reference coordinate system.

14. A system for eye gaze tracking comprising:

means for creating a set of reference points in a reference coordinate system;

means for acquiring at least one image of at least one of a user's corneas, said image having image aspects in an image coordinate system and including reflections of said reference points;

means for defining a mathematical relationship between said reference coordinate system and said image coordinate system;

means for mapping said image aspects from said image coordinate system to said reference coordinate system using said mathematical relationship; and

means for computing a point of regard from said mapped image aspects.

15. A computer program product including a program storage device readable by a machine, tangibly embodying a program of instructions executable by the machine to perform method steps for eye gaze tracking, said program comprising:

a first code means for creating a set of reference points in a reference coordinate system;

a second code means for acquiring at least one image of at least one of a user's corneas, said image having image aspects in an image coordinate system and including reflections of said reference points;

a third code means for defining a mathematical relationship between said reference coordinate system and said image coordinate system;

a fourth code means for mapping said image aspects from said image coordinate system to said reference coordinate system using said mathematical relationship; and

a fifth code means for computing a point of regard from said mapped image aspects.

* * * * *

Exhibit B

Exhibit B

aGlass

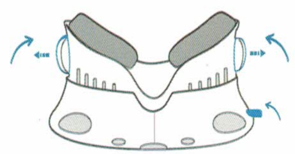
VR Eye Tracking Module aGlass DKII

Beijing 7invensun Technology Co., Ltd.
http://www.aglass.com/
400-880-1390
business@7invensun.com
Room 1801-1803 , JinHui plaza ,QiYang Road, Chaoyang District

Quick Instructions

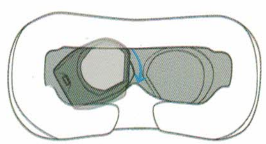
Tip : Please make sure that HTC Vive equipment works normally.

1



Adjust the Lens distance knobs to maximize the interior space of Vive. Adjust the IPD knob to maximize the interpupillary distance.

2



Take the left eye module for example: slightly rotate the module counterclockwise, upturn the narrow side over the lens, insert the wide side into the bottom left space, then slightly rotate it clockwise and plug it in when dovetailing with the base.

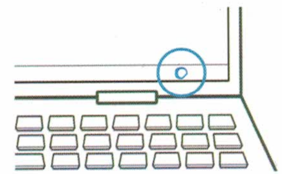
3

Open the compartment cover of Vive; connect the Vive and aGlass modules with aGlass Connector.

4

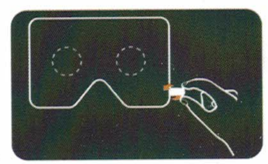
Visit http://www.aglass.com/download?lang=en&software=soft to download the SDK, decompress it, and double click Setup.exe to install it.

5



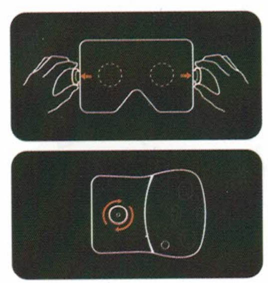
Launch the software and right-click in systray, then click "Calibration→9 points" or "Calibration→3 points". Put on the Vive.

6



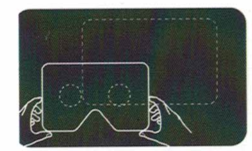
Adjust the IPD knob according to the instruction in the Vive scene.

7



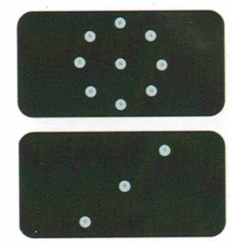
Pull out the lens distance knobs and adjust them according to the instruction in the Vive scene.

8



Adjust the Vive position relative your face according to the instruction in the Vive scene.

9



Calibrate according to the instruction in the Vive scene. You can use the gaze tracking after calibration.

Assembly Guide Video

Developer Center

Users Manual

Exhibit C

Exhibit C

7INVENSUN

aGlass™

aGlass VR Eye Tracking Add-on for HTC Vive

aGlass DK II

Users Manual

Beijing 7invensun Technology Co., Ltd.

www.aglass.com

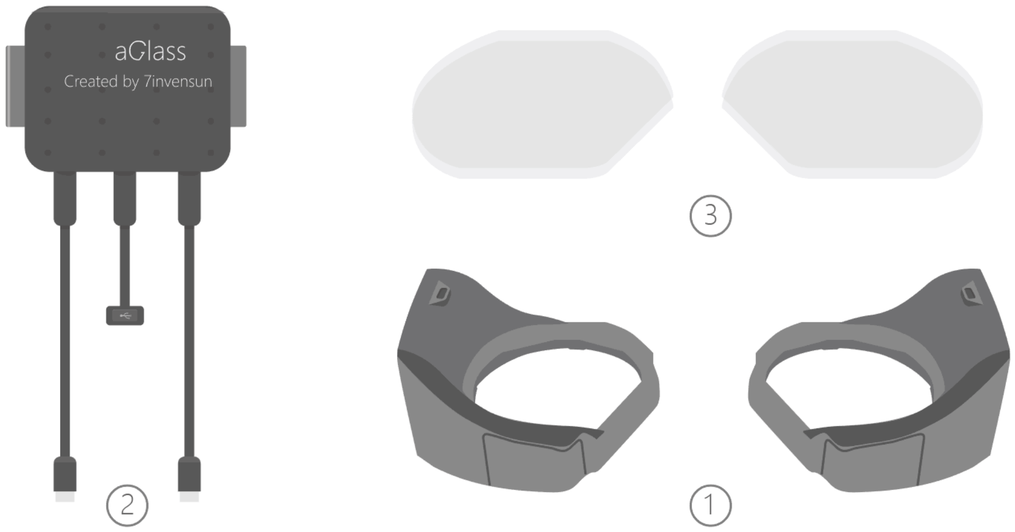
400-880-1390

business@7invensun.com

Room 1801-1803, JinHui plaza ,QiYang Road, Chaoyang District

Contents

1 Package Content



No.	Name	Amount
1	aGlass Add-on	A pair, one for left eye and another for right eye
2	aGlass Connector	1
3	Myopic lens	3 pairs (200 degree, 400 degree, 600 degree)
4	Users Manual	1
5	Service Card	1
6	Lens Cloth	1

2 Hardware Specification

- Adapted VR device: HTC Vive
- Accuracy: < 0.5°
- FPS: 100Hz/120Hz
- Delay: < 5ms
- Communication Port: USB2.0/3.0
- FOV: >110°

3 Environment Configuration

3.1 HTC Vive

aGlass has to be used after installed in HTC Vive, so please make sure that your HTC Vive is in normal operation, including the base station, headset, link box and controller etc. If your HTC Vive does not work normally, please click https://www.vive.com/us/support/.

3.2 Computer

Configuration Requirements:

- Desktop Computer GPU: GeForce GTX 970 or higher
- Laptop GPU: GeForce GTX 980 or higher
- CPU: Intel Core i5- 4590 or higher
- Memory: 8G or above
- Interface: 2 USB interfaces at least, 1 HDMI interface at least
- Operating System: 64-bit Windows 10

3.3 SteamVR

Please make sure that SteamVR is installed on your computer and works normally.

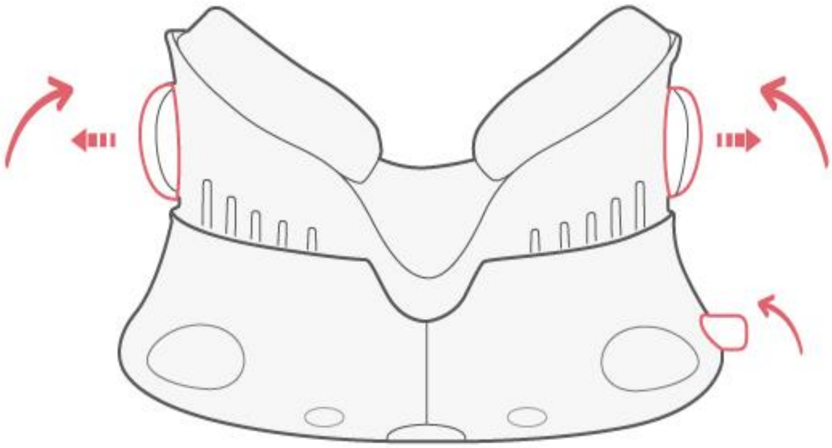
If you have not installed SteamVR, please click https://steamcdn-a.akamaihd.net/client/installer/SteamSetup.exe. to download and install Steam, and then install SteamVR in Steam.

4 Hardware Assembly

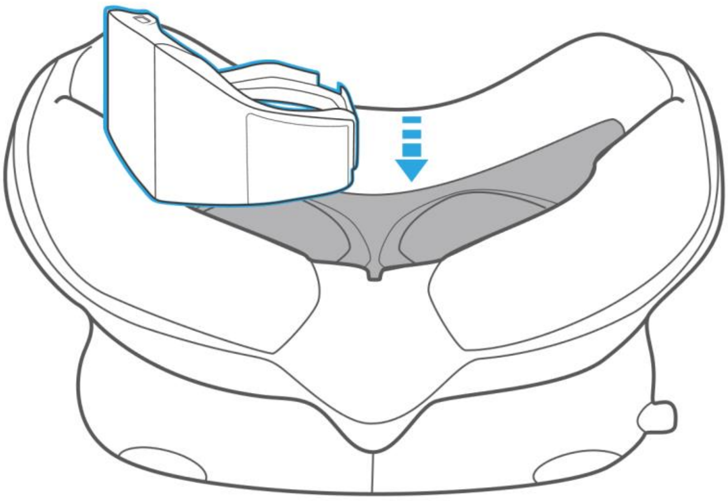
4.1 Assembly of aGlass Add-on

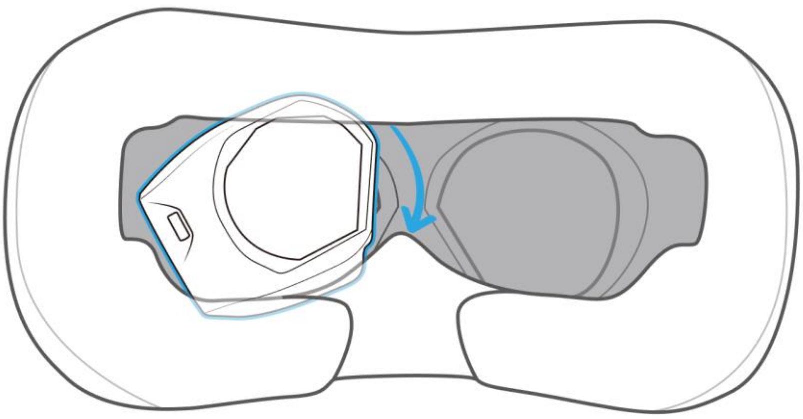
Click http://www.aglass.com/assets/aGlass-DKII-Assembly-Guide-Chs.mp4 to learn how to install the product.

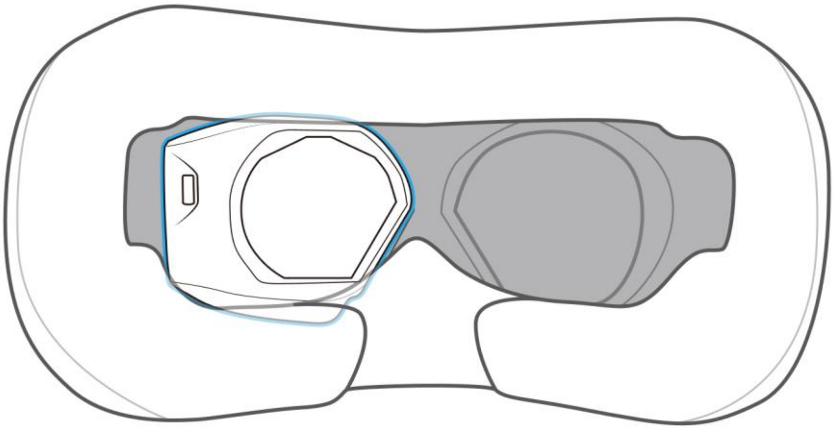
1) Rotate the lens distance knobs on both sides of the HTC Vive headset, to maximize the lens distance. Rotate the IPD (interpupillary distance) knob of HTC Vive, to maximize the IPD.



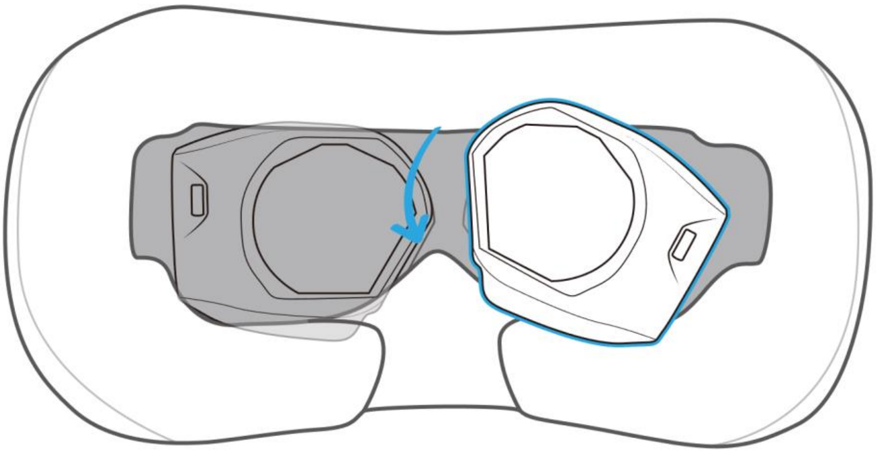
2) When installing the eye-tracking add-on for the left eye, put it above the HTC Vive lens, with the thin side of the aGlass add-on upward (compared with the angle of the HTC Vive lens base, slightly rotate anticlockwise to a certain angle), rotate clockwise while embedding it with the thick side downward, and adjust the position of accessories, to finally fix the add-on at the position above the lens.

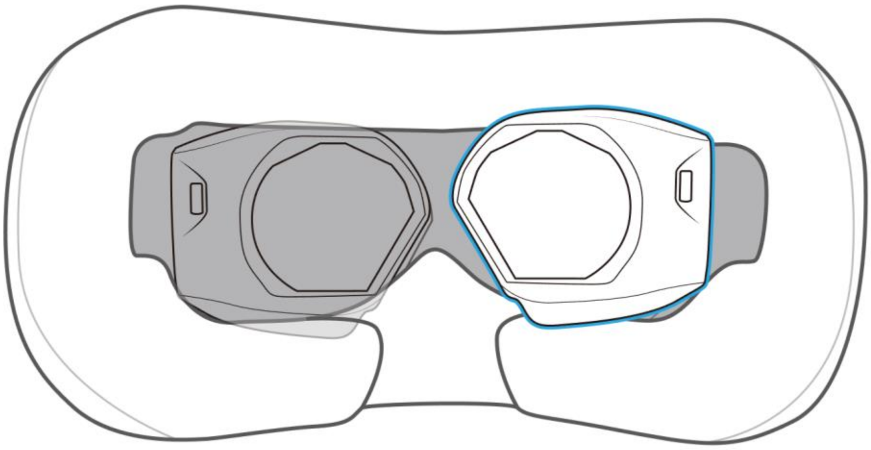






3) The eye-tracking add-on for the right eye is installed in the same way as that for the left eye, but aligned and rotated in the opposite direction.

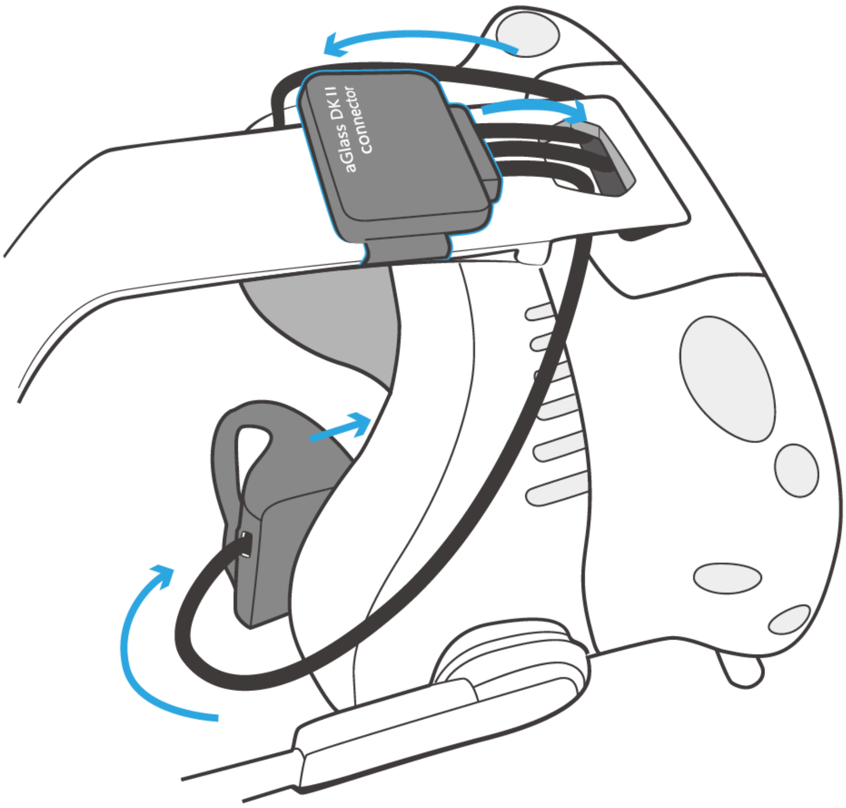




4. 2 aGlass Connector Installation

Fix the connector on the Vive strap through connector buckle. Put Vive cable under the slot of the connector.

Power off the Vive. Open the compartment cover on the top of the Vive. Connect the shorter USB cable to the reserved USB interface of Vive. Put the two longer USB cable through the Vive strap hole and connect to the two aGlass add-ons.



5 Software Installation

Click http://www.aglass.com/download?lang=en&software=soft to download aGlass Runtime.

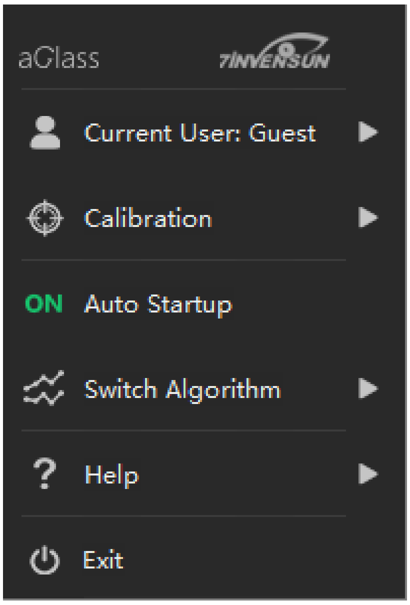
After the download and extraction, double click Setup.exe to install the software according to the prompts.

Note: You must log in the Windows operating system and install it as the administrator, or else you may make the software run abnormally.

6 How to Use

6.1 Start Software

Double click the aGlass Runtime shortcut on the Windows desktop, to start the aGlass Runtime program, and the icon will appear in the system tray. The following menu will appear by a right click on the icon in the tray:



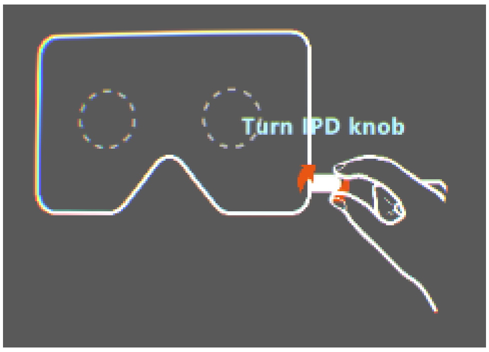
6.2 Calibration

Click Calibration and choose 9-Point Calibration or 3-Point Calibration in the right click menu.

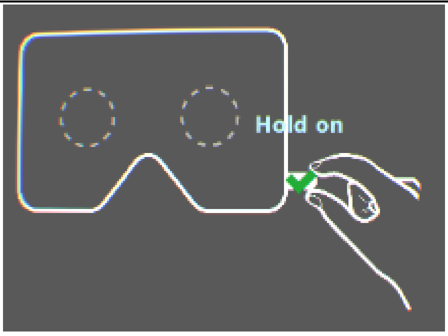
Wear the HTC Vive headset, and perform the following procedures according to the prompts on the interface:

6.2.1 IPD Adjusting

Put on the Vive HMD. IPD adjust guidance will be seen, like shown below:



Turn the IPD knob according to the instruction in the Vive scene. Stop turning if the following scene displayed:

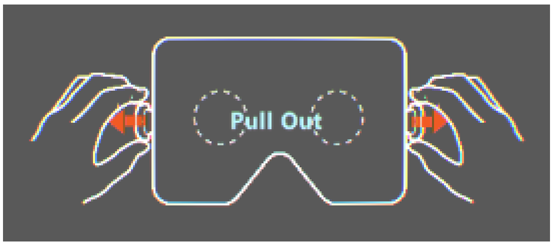


Hold on to wait the next step.

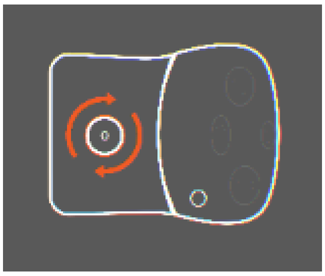
6.2.2 Adjusting of the Lens Distance

The lens distance adjusting scene will show after the IPD adjusting. If the lens distance is OK, this scene will be skipped.

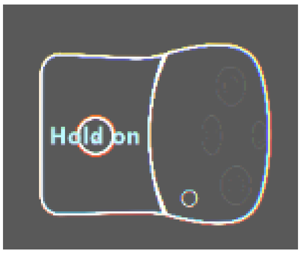
Pull out the lens distance knob first following the display:



Turn the lens distance knob according to the image in the scene:

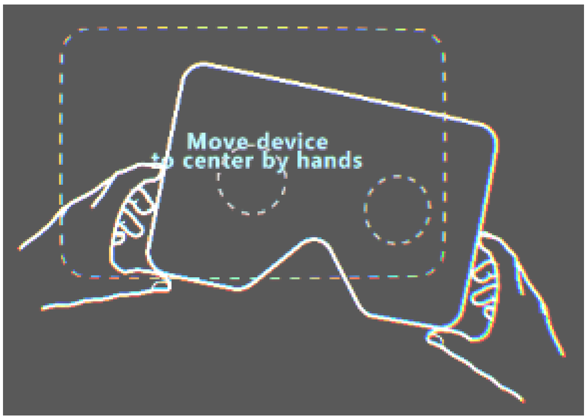


Stop turning when the "Hold on" displays as shown below, and wait the next step:

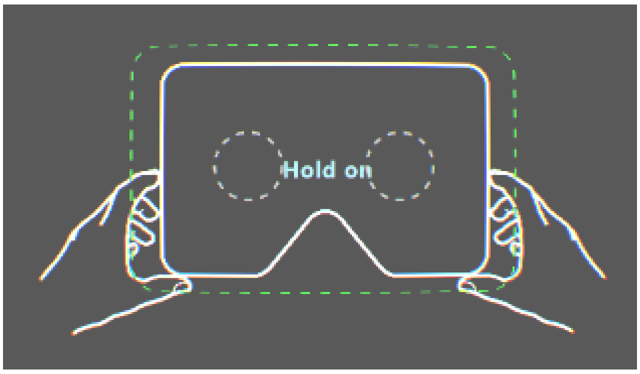


6.2.3 Position Adjusting

The position adjusting scene will be shown after the lens distance adjusting. Please adjust the Vive HMD position relative your face according to the instruction in the scene:



When Vive HMD move to the appropriate position, the scene become:



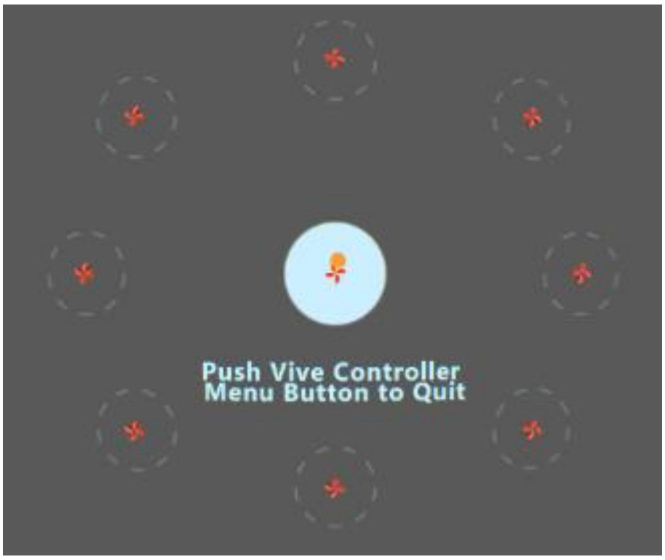
Wait for a moment to next step.

6.2.4 Calibration

On calibration, you need to keep watching the calibration point (as shown in the figure below) that appears:

6.2.5 Verification

You can judge whether the calibration is accurate.



Press the menu button of the HTC Vive controller or the ESC key on the keyboard to quit the calibration.

6.3 User Management

The system provides a default user account Guest, but it is recommended to create your own user account.

By clicking "Current User -> Create a User", you can create a new user account, which will automatically enter the calibration procedure.

During use, please switch user accounts if users change.

7 Vision Corrective Lens

We provide myopic lenses, the default degrees of which are 200°, 400° and 600°; users can also get myopic lenses of different types and degrees through our customization service.

How to install the myopic lenses: according to the shape of the lens, gently put the lens into the aGlass add-on and fixed it in the middle with its convex surface downward.

How to dismantle the myopic lenses: find the edge of the lens at the gap in one side of the add-on, where the lens can be taken out by hand.

8 Disassembly and Maintenance of the Product

8.1 Disassembly of the Add-on

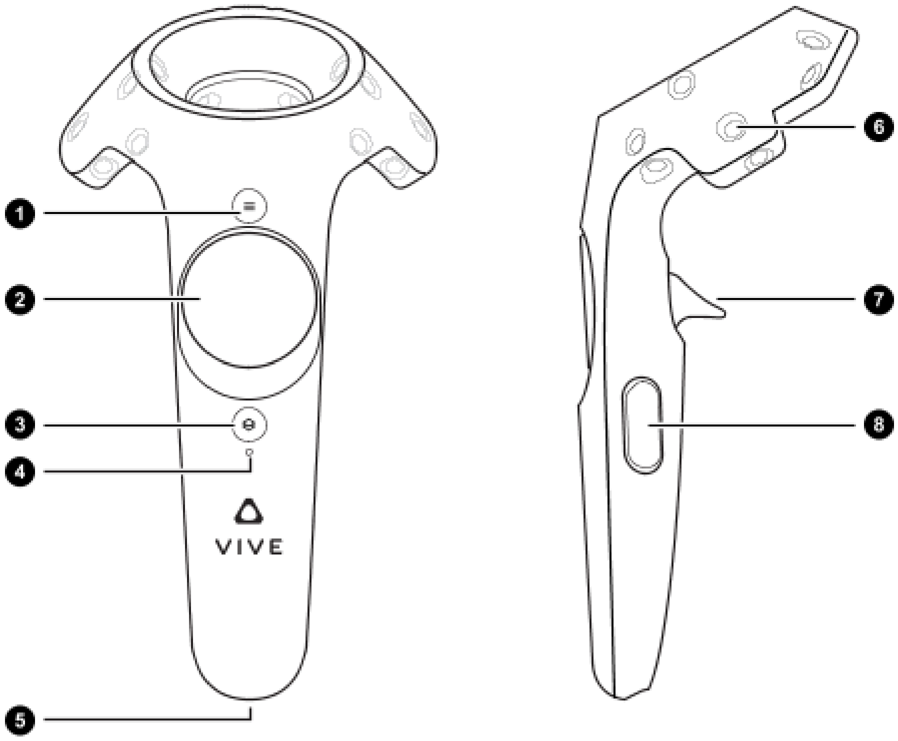
Click http://www.aglass.com/assets/aGlass-DKII-Assembly-Guide-En.mp4 to learn how to disassembly the product.

1) Power off the Vive. Disconnect the USB wire between aGlass connector and Vive. Disconnect the USB wire between aGlass connector and aGlass Add-ons.
2) Rotate the lens distance knobs on both sides of the HTC Vive headset, to maximize the lens distance.
3) Rotate the IPD (pupillary distance) knob of HTC Vive, to maximize the IPD.
4) Lift the thick and thin sides of the aGlass add-on for the left eye upward successively, to loosen it from the HTC Vive lens, after which gently rotate anticlockwise while lifting upward until the lower end of the aGlass add-on is loosened, to finally take out the add-on completely; take out the aGlass add-on for the right eye from the other side in the same way but rotate clockwise.

8.2 Precautions

1) Hot plugging not supported. Please power off the Vive before plugging or unplugging USB interface.
2) Please store and use the product at room temperature.
3) Do not expose the product in rain or moisture conditions.
4) Do not throw, to avoid damage to the product caused by falling.
5) Do not disassemble, repair or modify the product by yourself.
6) Do not wipe the product with any chemical solvent.
7) Do not throw the product away or put it in high temperature (higher than 60°C) or fire to avoid danger.

8.3 Vive Controller Button Definition



1) Menu button
2) Trackpad
3) System button
4) Status light
5) Micro-USB port
6) Tracking sensor
7) Trigger
8) Grip button

9 Biosafety Statement

aGlass DK II uses the way of infrared lighting (wavelength 850 nm).

aGlass DK II has passed the certification of international standard IEC 62471: the photobiological safety of lamps and lamp systems. It's confirmed that aGlass DK II will not cause any harm to the human eyes and body.

Warning: The injuries of infrared lights to the eye lens and retina have two kinds: long-term

and short-term. The existing research does not ensure that long time infrared radiation has no effect on human eyes. So, don't use the product for too long time and pay attention to eye health.

10 Troubleshooting

1) Questions: Paper user's manual is not very detailed. Are there any instructions more detailed?
   Answers: Click the following link for more instructions:
   http://www.aglass.com/assets/aGlass-DKII-Users-Manual-En.pdf.
   If you are developer or want to know the API, click the following link:
   http://www.aglass.com/assets/aGlass-DKII-Developers-Guide-En.pdf。
2) Questions: I cannot install the add-ons onto the HTC Vive Headset.
   Answers: Click http://www.aglass.com/assets/aGlass-DKII-Assembly-Guide-En.mp4, to watch the video on how to install and disassemble the add-on, and operate by following the operating procedures shown in the video.
3) Questions: I cannot calibrate the device as the calibration options in the menu are all gray.
   Answers: Check whether the HTC Vive is plugged in and power on.
   Check whether the add-on and HTC Vive are connected properly with the USB cable.
4) Questions: When starting calibration, I received a prompt of OpenVR failure.
   Answers: Check whether you have installed and logged on to SteamVR, and if you haven't, please install and log on to SteamVR, to test whether HTC Vive can work normally under SteamVR.
5) Questions: When starting calibration, I received a prompt of not finding the USB key.
   Answers: Check whether the USB key is normally inserted into the USB interface of the computer in use, and try pulling out and inserting it again.
6) Questions: During calibration, there is a point that always fails to pass.
   Answers: Pressing grip button of HTC Vive controller or clicking W on the keyboard can force it to pass, or wait for it to pass automatically after 15 seconds.
7) Questions: I want to take the add-on off from HTC Vive, but always fail.
   Answers: Click http://www.aglass.com/assets/aGlass-DKII-Assembly-Guide-En.mp4, to watch the videos on how to install and disassemble the add-on, and operate following the operating procedures shown in the video.
8) Questions: Can I wear my glasses or not while using it?
   Answers: It is not recommended to wear glasses when using it. We can provide myopic lenses of 200°, 400° and 600°, and if these cannot meet your demand, you can also order customized myopic lenses from our company and install them into the add-on.
9) Questions: What are the precautions for use?

Answers: Make sure the HTC Vive power on and connected normally.

Ensure that the aGlass add-on is installed correctly and steady.

Ensure that the nose rest does not influence the installation of the add-on, or cover the sensor under the add-on.

Ensure that the USB cable is normally connected, to avoid any faulty connection.

Ensure that there is nothing between the eyes and the lenses in the headset.

Ensure that you have normally installed and logged on to SteamVR.

Avoid stamping the HTC Vive cable while using it.

11 Trademarks and copyright

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2) Steam, the Steam logo and Steam VR are trademarks and/or registered trademarks of Valve Corporation in the U.S. and/or other countries.
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Exhibit D

Exhibit D

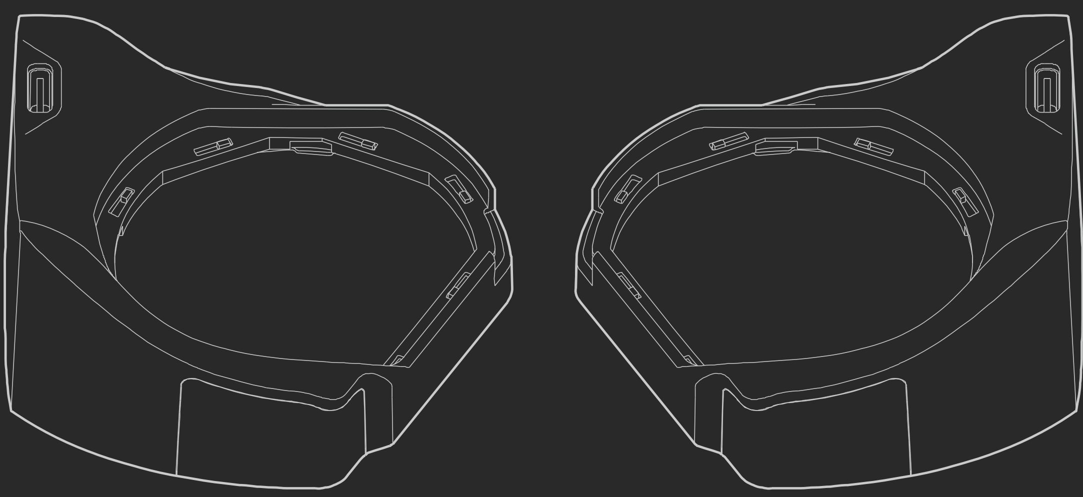
7INVENSUN

aGlass™

aGlass VR Eye Tracking Module for HTC Vive

aGlass-vi-1

Users' Manual



Beijing 7invensun Technology Co., Ltd.

January 2017

Contents

1 Preface

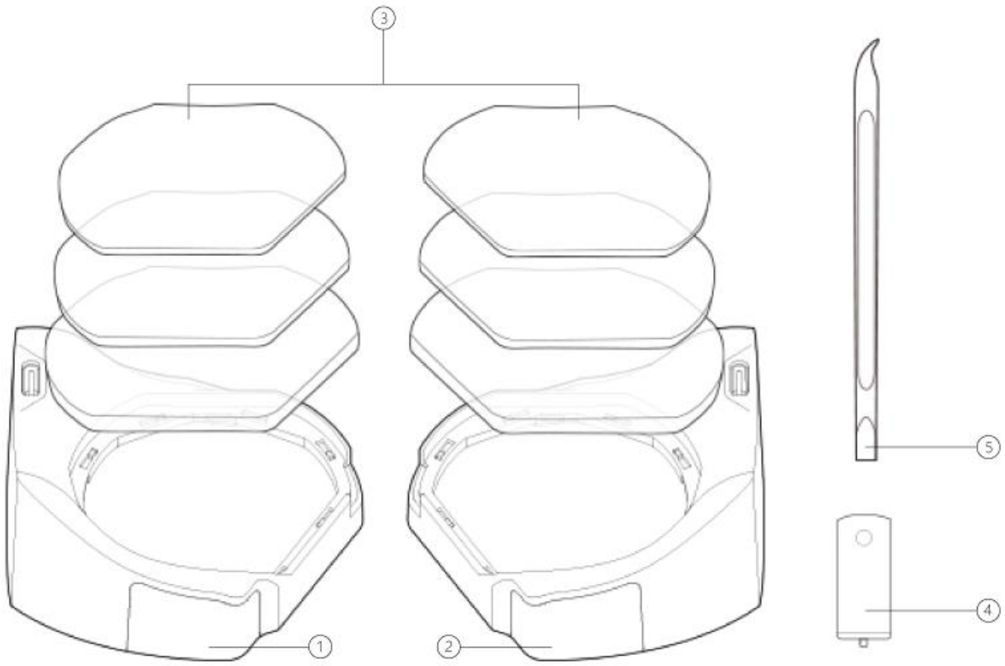
Dear users,

Thank you so much for choosing 7invensun VR eye tracking module aGlass-vi-1. aGlass-vi-1 is only adapted for VR HMD HTC Vive. Please read the instructions carefully before use to better exert the superior performance of the product.

2 Cautions

- Please keep or use this product at normal temperature.
- Do not expose this product in rain or moisture.
- Do not throw this product to avoid any damage.
- Do not disassemble, repair or reform this product by yourself.
- Do not clean this product with any chemical solvent.
- Do not throw away and do not put it in high temperature (higher than 60°C) or fire to avoid danger.

3 Product List



1) aGlass module for left eye
2) aGlass module for right eye
3) Myopic lens：3 pairs (200 degree, 400 degree, 600 degree)
4) USB key
5) Lens disassembly tool

And:

- Lens cleaning cloth
- USB cable
- User manual

4 Hardware Specification

- VR Device Adapted: HTC Vive
- Precision: < 0.5°
- Fame frequency: 120Hz
- Delay: < 10ms
- Interface: USB 2.0, one end with Type B, one end with Type C
- FOV: >110°

5 Computer Configuration Requirements

- Desktop Video Card: GeForce GTX 970 or higher
- Laptop Video Card: GeForce GTX 980 or higher
- CPU: Intel Core i5- 4590 or higher
- Memory: 8G or more
- Interface: 3 USB 3.0 interfaces, 1 HDMI 1.3 interface
- OS
  - 64bit Windows 7
  - 64bit Windows 10

6 Assembly and Disassembling

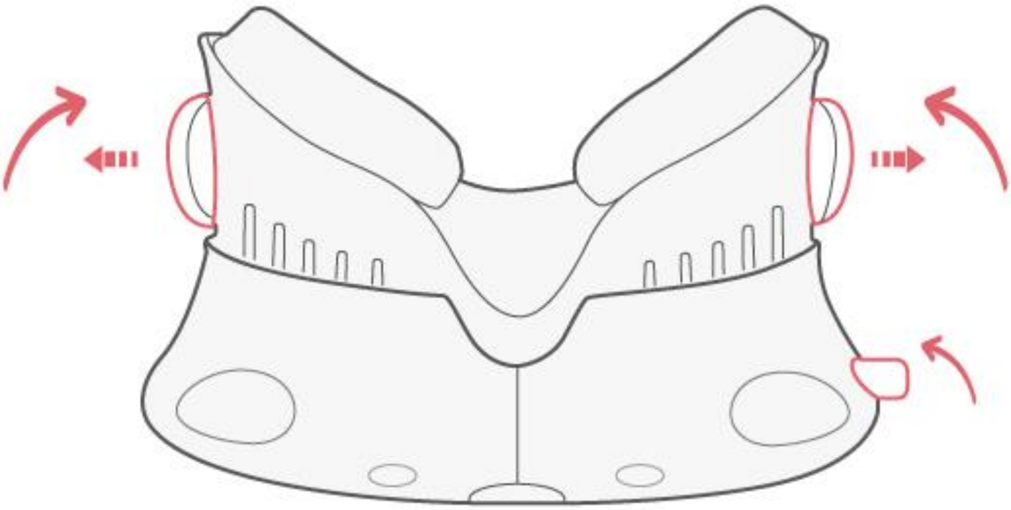
6.1 Guide Video

Please open the web site www.aglass.com/user. The video on the web has the detailed process demonstration of assembly and disassembling of the product.

6.2 Assembly

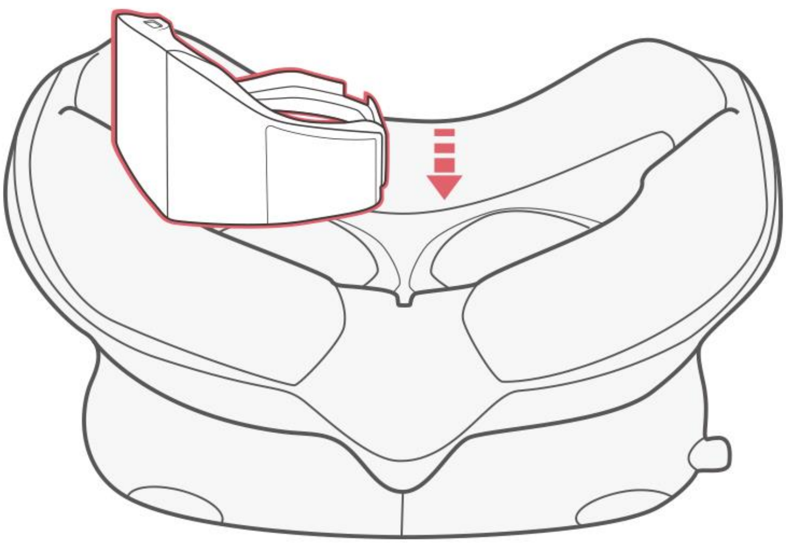
1) First of all, on the basis of ensuring the module being in good condition, unpack the external package and place the module on a stable table in a gentle manner.
2) Hold HTC Vive in the front, direct the inner side at yourself. The operation shall be done with eyes level.
3) Turn the lens distance knobs on both sides of HTC Vive to the maximum. When it reaches about to the maximum, turn the knob gently. Be careful to avoid overexertion damage.

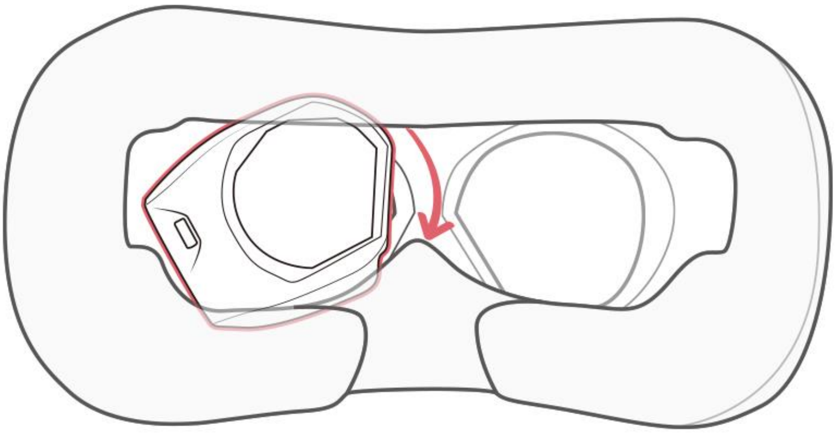
4) Turn the IPD (interpupillary distance) knob beneath HTC Vive clockwise to the maximum. When it reaches about to the maximum, turn the knob gently. Be careful to avoid overexertion damage.

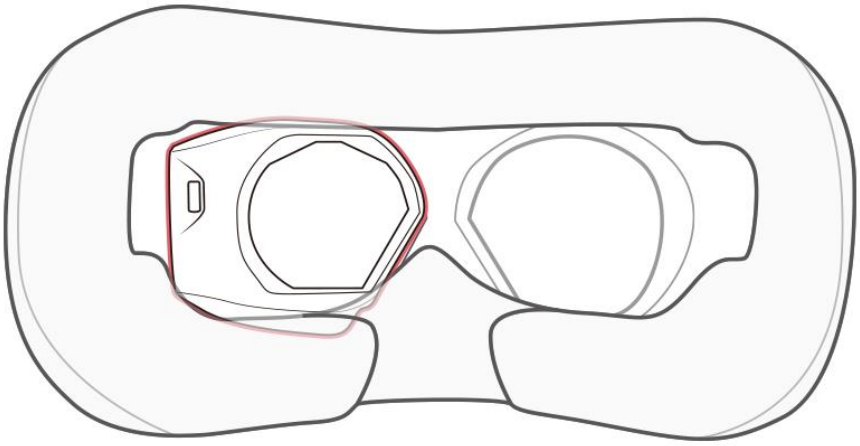


5) Support the lower part of the apparatus with left hand, with eyes directed to the inner side horizontally. Break apart the nose rest with thumb and press it without loosening, the other four fingers support the apparatus stably.

6) Pick up the prepared left eye aGlass module with right hand. Place the narrow side upward into between the HTC Vive face cushion and lens. Then place the wide side into it while turning the module clockwise. Adjust position of the module until it is fixed on the position beneath the face cushion above lens. It shall be ensured that the narrow side is placed on the inner side, and the wide side on the outer side (in conformity to the inner lowness and outer highness of the radian of aGlass module).







7) Assembly the right eye module as the same method, but the turning direction is anticlockwise when put the module into the HTC Vive.

8) Open the lid above the HTC Vive, and connect the USB Type B end to the reserved USB Socket, and make the cable pass through the wire guide.

9) Connect the USB Type C end to aGlass eye tracking module and ensure it firm.

6.3 Disassembling

1) First of all, place HTC Vive on a stable table in a gentle manner.

2) Hold the HTC Vive in the front, direct the inner side at yourself. The operation shall be done with eyes level.

3) Turn the lens distance knobs on both sides of HTC Vive to the maximum. When it reaches about to the maximum, turn the knob gently. Be careful to avoid overexertion damage.

4) Turn the IPD (interpupillary distance) knob beneath HTC Vive clockwise to the maximum. When it reaches about to the maximum, turn the knob gently. Be careful to avoid overexertion damage.

5) Support the lower part of the apparatus with the left hand, with eyes directed to the inner side horizontally. Break apart the nose rest with thumb and press it without loosening, the other four fingers support the apparatus stably.

6) Firstly, lift up the narrow side of left eye aGlass module, until it loosens from the HTC Vive lens. Then turn it anticlockwise gently, until the bottom part of aGlass module loosens and emerges, take out the whole module. Take out the right eye aGlass module on the other side in the same way.

7) After the aGlass module is taken out and maintained, place it in clean and dampproof area away from light, for next-time use.

6.4 Assembly of Vision Corrective Lens

1) From the three pairs of lens, choose the one fitting yourself.

2) Make sure that your hands are clean, take out the lens. With convex surface of the lens downward, place the lens into the center of VR eye-tracking module in a stable condition according to the shape of the lens gently.

6.5 Disassembling of Vision Corrective Lens

1) Firstly, place HTC Vive on a stable table in a gentle manner.

2) Make sure that both hands and table top are clean, take out lens disassembly tool. Choose the curved thin end, then, at the groove on the inner side of module, pry the inner side gently, to loosen the lens, then take out the lens with finger pulp gently.

3) The lens shall be washed and wiped clean, before it is placed in the box, for use next time.

7 Software Download and Installation

Note: The screen shots in this manual are under Windows 10.

7.1 Download

Runtime software download site: www.aglass.com/download.

7.2 Installation

After the download, double click Setup.exe to start installation.

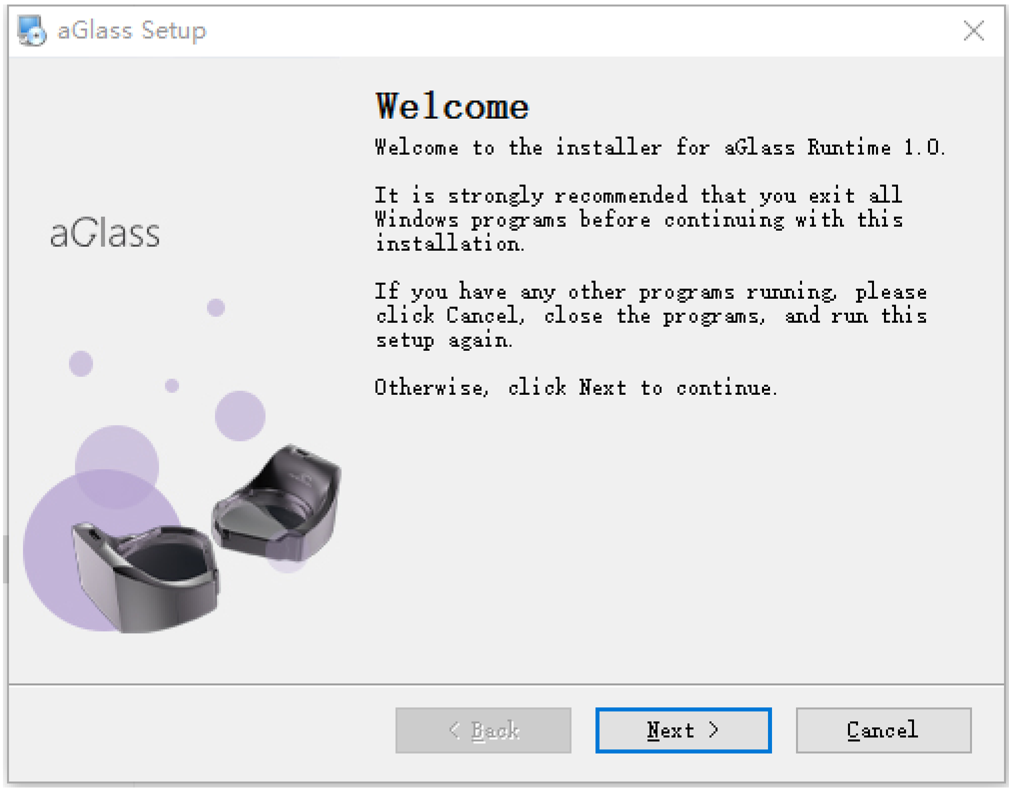
Note: You must login the Windows OS and install aGlass Runtime by administrator authority, or the aGlass Runtime may malfunction.

The first step is welcome, operations:

- Next: continue to next step.
- Cancel: stop the installation.

The interface is shown below:

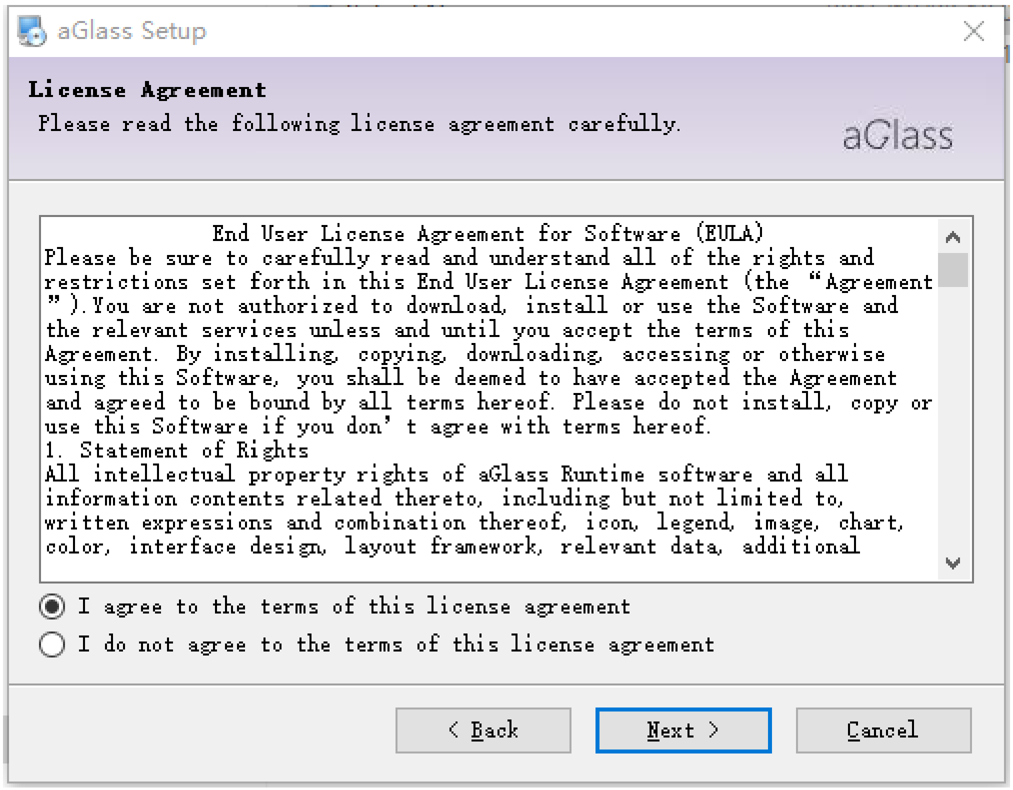
7INVENSUN



The next step is license agreement, operations:

- Next: continue to next step if you choose "I agree to the terms of this license agreement".
- Back: return to the previous step.
- Cancel: stop the installation.

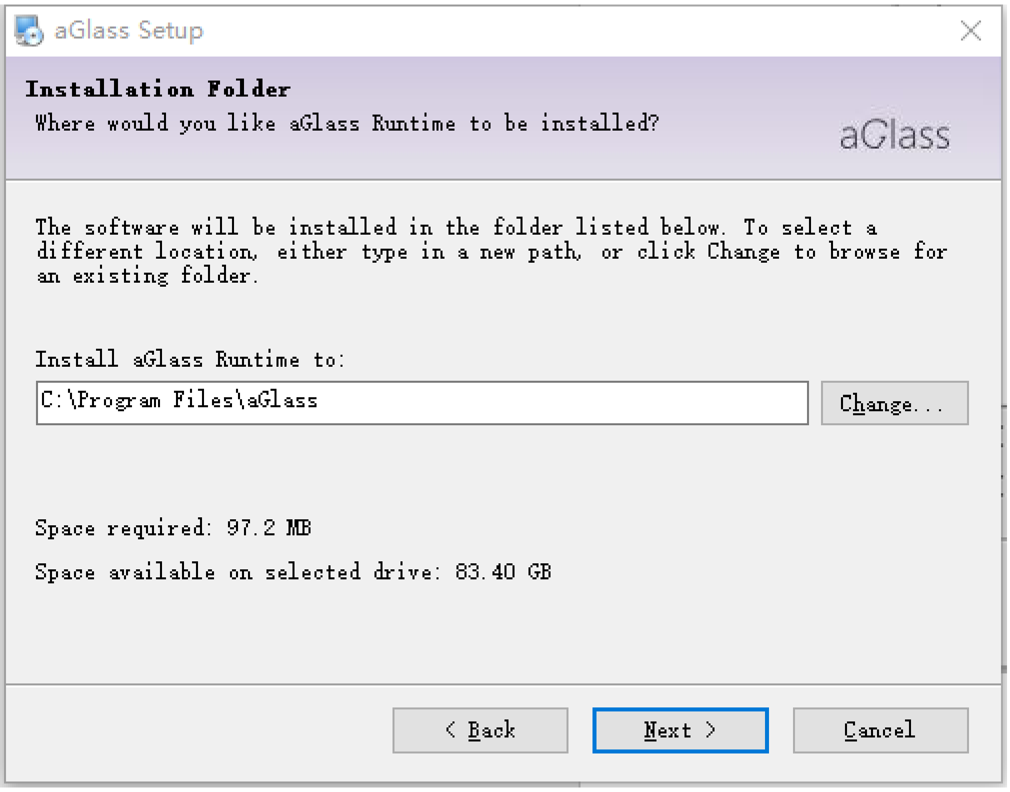
The interface is shown below:



The next step is installation path choosing, operations:

- Set installation path: input the path directly or click Change to choose the path.
- Next: continue to next step.
- Back: return to the previous step.
- Cancel: stop the installation.

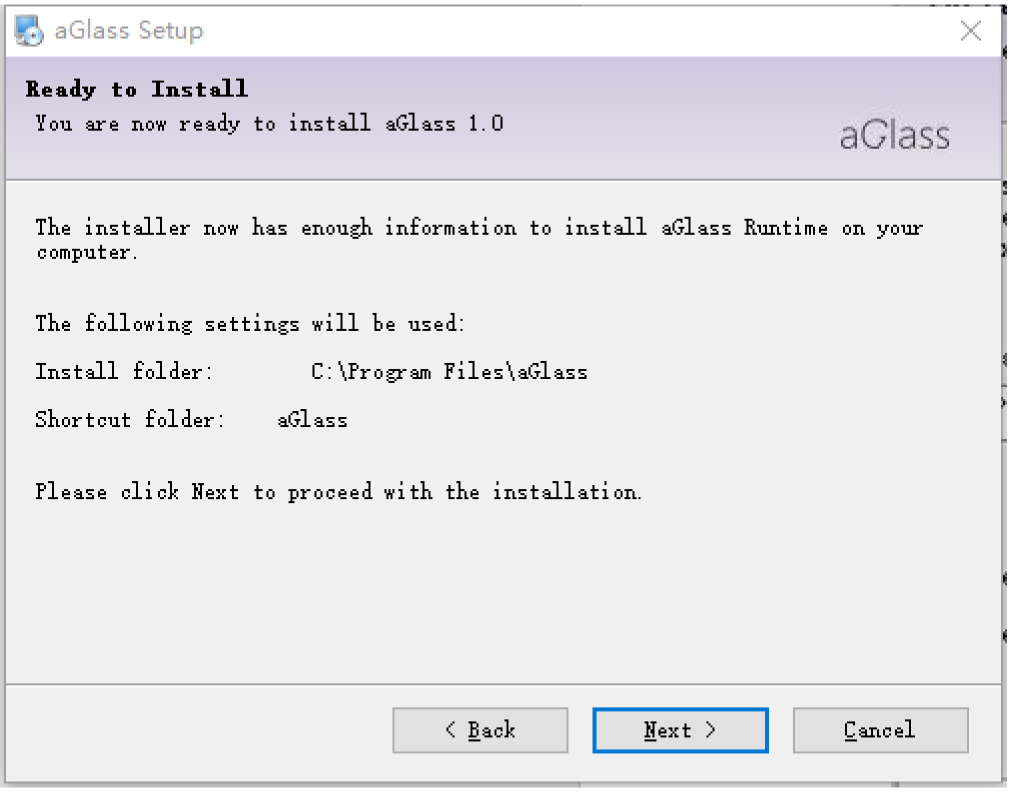
The interface is shown below:



The next step is ready to installation, operations:

- Next: continue to next step.
- Back: return to the previous step.
- Cancel: stop the installation.

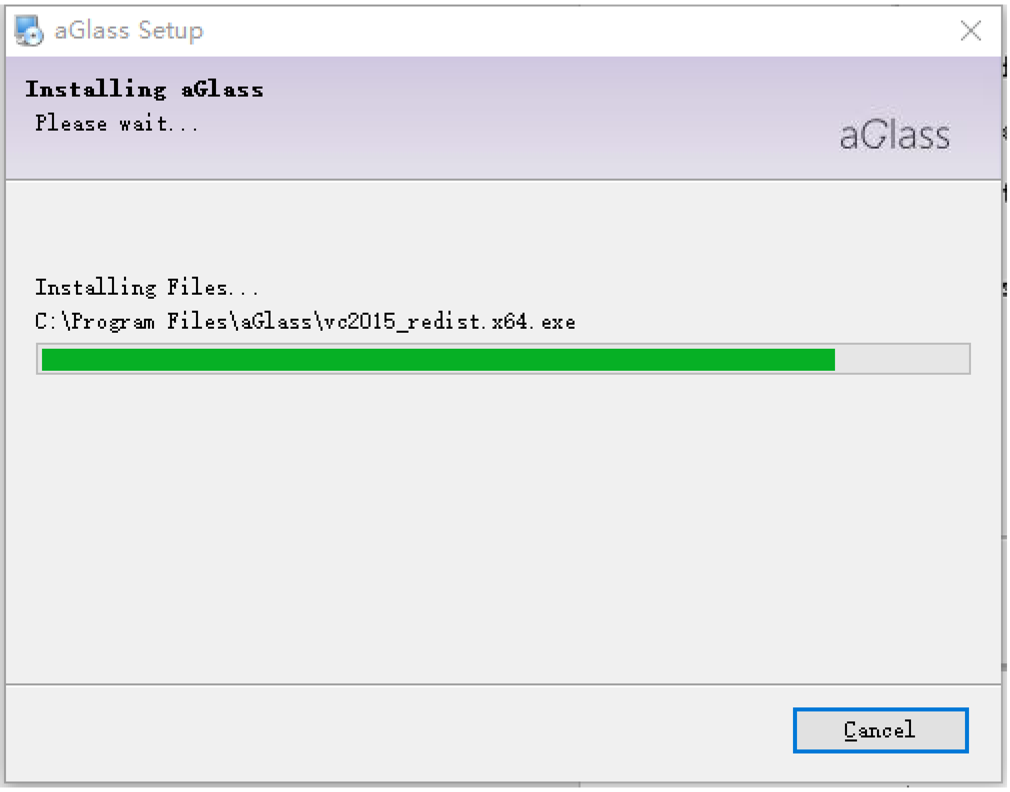
The interface is shown below:



The next step is installing, you should wait for a moment while the program is installing, operation:

- Cancel: stop the installation.

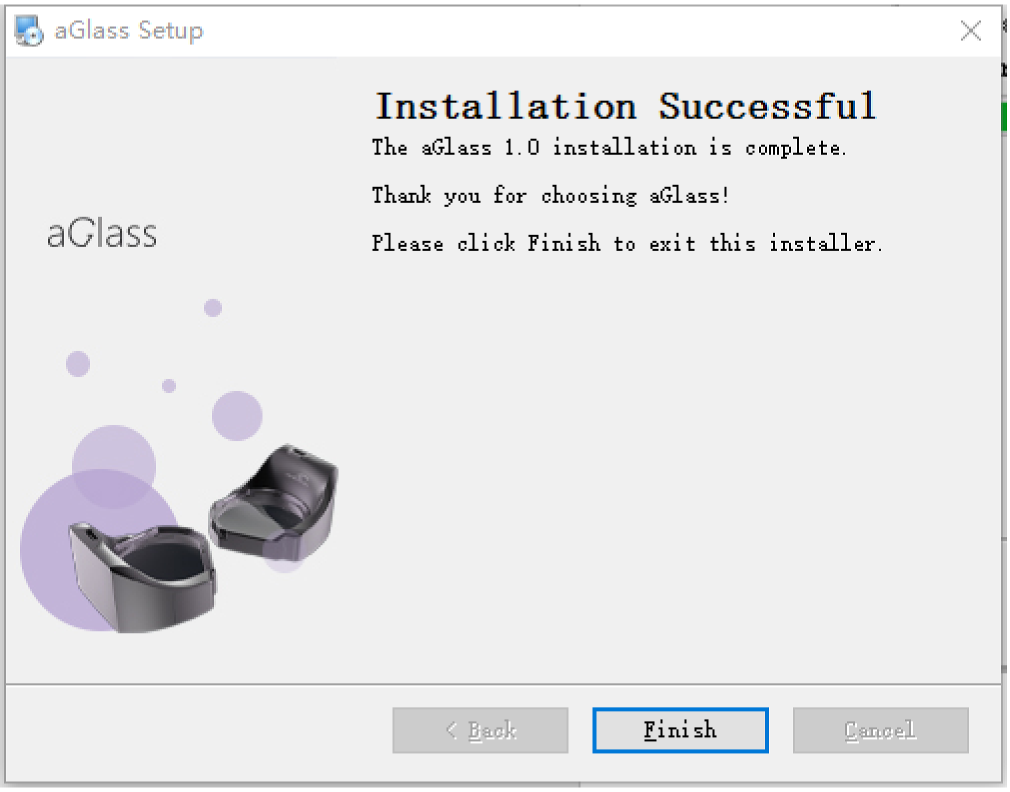
The interface is shown below:



The next step is installation complete, operation:

Finish: complete and exit the installation.

The interface is shown below:



7.3 Environment Setup

For aGlass Runtime working, Steam and SteamVR is need to be installed. You can download Steam and SteamVR from http://steamcommunity.com/ and install them.

For aGlass Runtime working correctly, follow the steps below:

- HTC Vive assembly correctly according to its user manual
- aGlass module is assembled and connected correctly
- aGlass USB key plugs in the computer correctly
- Start SteamVR (Note: Ensure that SteamVR starts and works correctly before aGlass Runtime)
- Start the aGlass Runtime

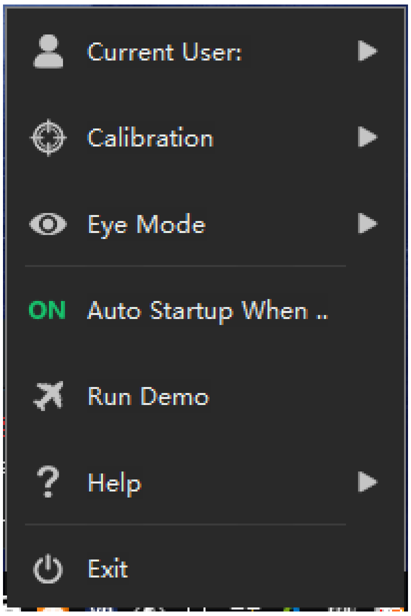
7.4 Startup

You can launch aGlass Runtime by click shortcut icon , and aGlass Runtime icon will show up inside the system tray, and a balloon message as shown below:

The balloon message will be disappear in 3 seconds.

The functions of aGlass Runtime includes mainly calibration, users management, eye mode setup and running demo.

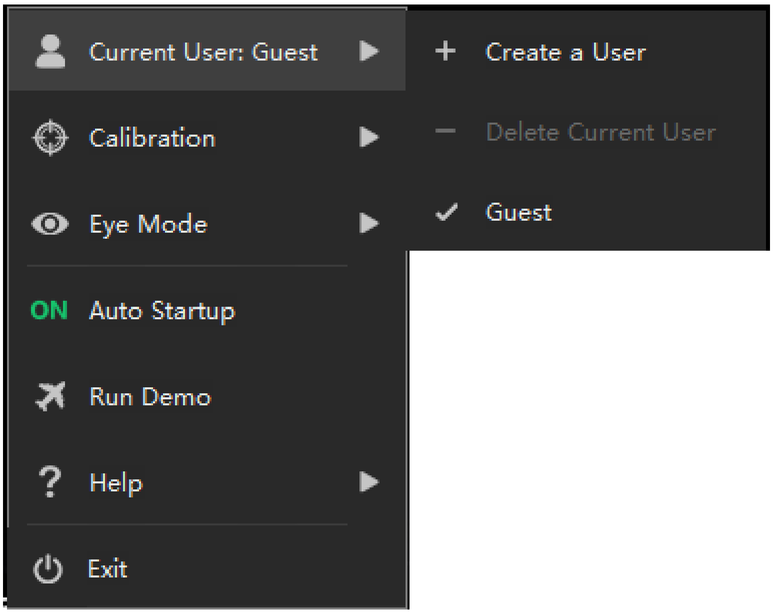
Right click the aGlass Runtime system tray icon, menu will be display as shown below:



8 User Management

8.1 Create User

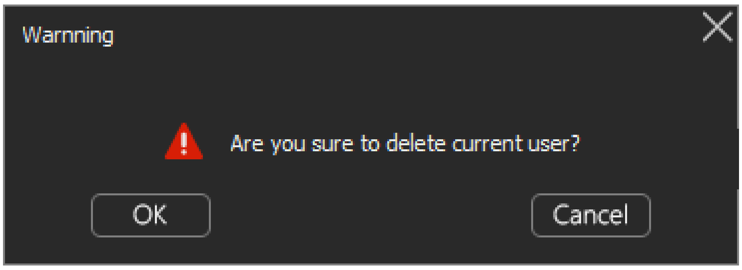
There is a default user "Guest" in the system, but it is recommended for users to create own account, so as to use fixation points more accurately, and also to be convenient for multiple users.



Click "Current User -> Create a User", you can create a new user account.

8.2 Delete Current User

If you hope to delete some user account, please switch it to the current user at first, then click “Delete Current User”.



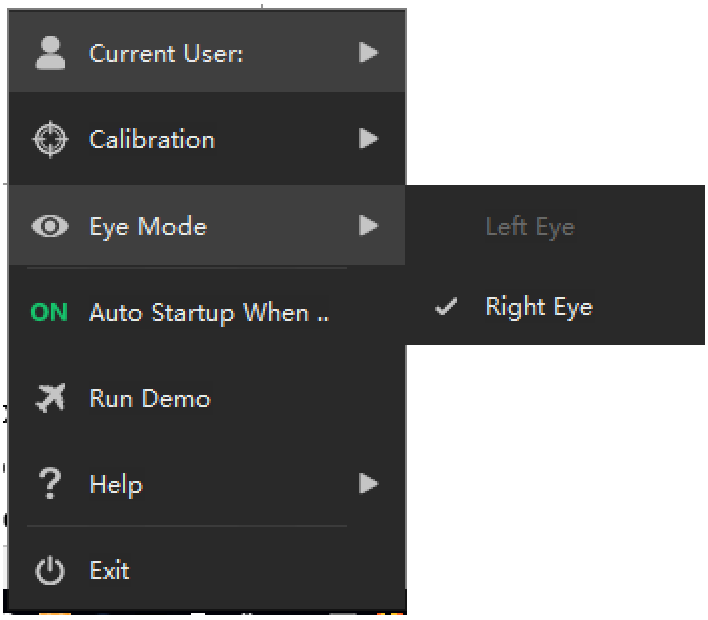
The user will be deleted if you click confirm.

8.3 Switch User

During the process, if you want to change the user, account switch is required. Because different users’ calibration data varies from each other, and if employing others’ account, maybe the gaze point will be incorrect, resulting in poor performance.

9 Eye Mode Option

After the module is assembled, click on “Eye Mod” menu of Runtime to show the options, please choose the option according to your module assembled.



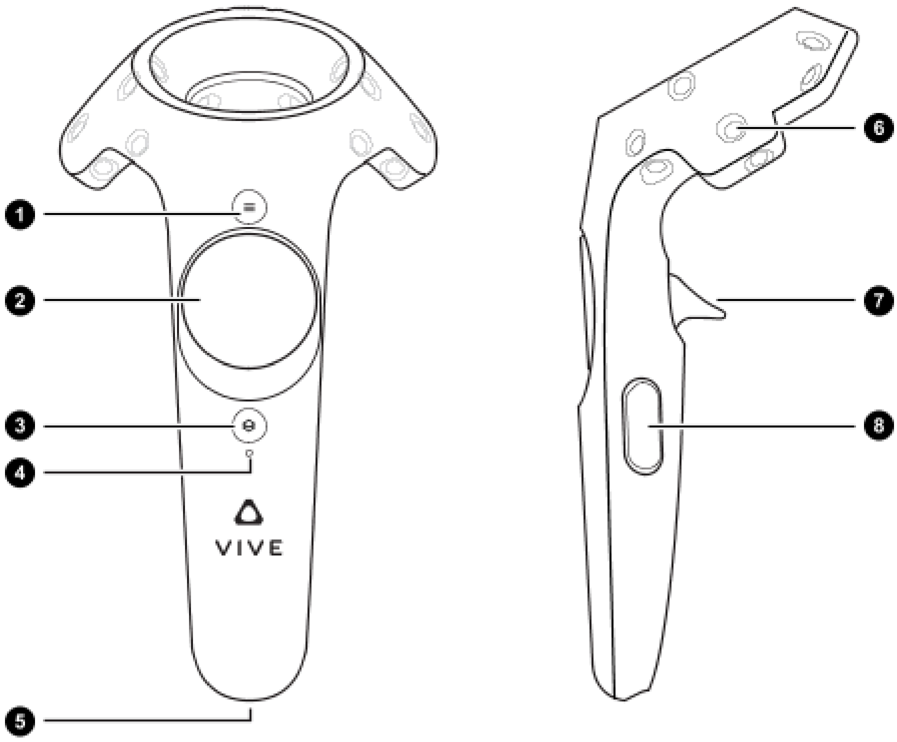
10 Calibration

Because people's eye feature is different from one another, calibration is needed for better use of aGlass after user creation and eye mode setup. You can choose user account Guest and make no calibration of course, but it's recommended for you to create your own user account and calibration.

Click "Calibration" in menu, "9-Point Calibration" and "3-Point Calibration" will be displayed. 9-point calibration is more accuracy than 3-point calibration and 3-point calibration is rapider than 9-point calibration. You can choose according to the up-application's request for accuracy.

After clicking "9-Point Calibration" or "3-Point Calibration", you can take on the HTC Vive HMD and see the scenes on the HMD's screen, then you should operate according to the tips on the scenes.

You can use keyboard or HTC Vive controllers to operate the calibration. HTC Vive controllers buttons definition:



1 Menu button

2 Trackpad

3 System button

4 Status light

5 Micro-USB port

6 Tracking sensor

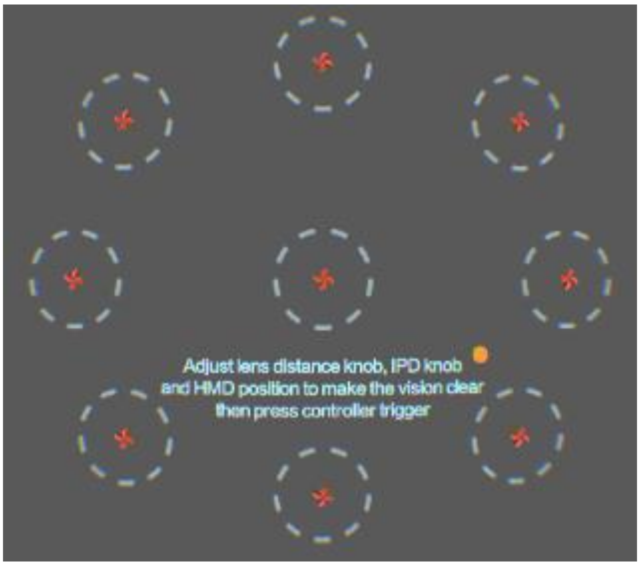
7 Trigger

8 Grip button

10.1 Device Adjustment and Gaze Point Verification

Device adjustment and gaze point verification scene displays in HTC Vive HMD first.

In the scene, there are some verification points and the dots indicating gaze point and the tip for adjusting device, as shown below:



Please adjust the visual range, pupillary distance and wearing gesture to make your view clear.

The distance between peripheral circles and central circle will be the distance between calibration points. Check if your eyes can see all the circles in the view. If you can't see the peripheral circles, you can click downward key on keyboard or trackpad downward on HTC Vive controller to reduce the distance of the circles.

If you have already done the calibration before, you can check if the calibration is accuracy. If the gaze point has been accuracy, click ESC on keyboard or menu button on HTC Vive controller to exit the calibration procedure.

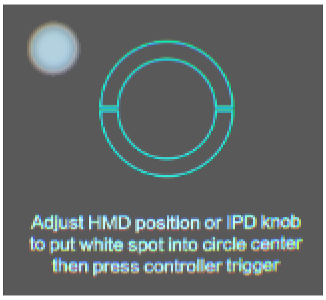
If you want to calibrate, click the space on key board or trigger on HTC Vive controller to enter the next scene "Pupil Alignment".

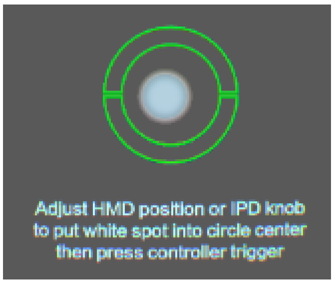
The operation methods in this scene sums up as follows:

Functions	HTC Vive Controller	Keyboard
Increase the distance between the peripheral circles and central circle.	Trackpad Upward	Upward
Decrease the distance between the peripheral circles and central circle.	Trackpad Downward	Downward
Revert to default distance between the peripheral circles and central circle.	Trackpad Rightward	Rightward
Exit the calibration	Menu button	ESC
Next step	Trigger	Space

10.2 Pupil Alignment

The interface of “Pupil Alignment” is shown below:

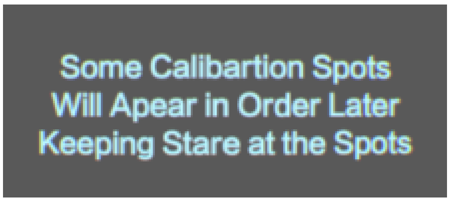




Users adjust the device to move the white spot into the center of the circle. When the white spot is within the circle, the circle will turn green, as shown in the picture. Then you can click space on keyboard or trigger on HTC Vive controller to continue to calibration.

10.3 Calibration

A tip will appear first, as shown below:



The tip will display for 10 second, then number count backwards 3, 2, 1 display in the center of the scene, and then the first calibration point will appear, as shown below:

Some calibration points will appear in turn in the scene. Please insure that you stare at the red spiral sector center. If you do this, the calibration point will shrink and disappear and move to another position, your gaze should follow it and always stare at the red spiral sector center. During the process, if you don't stare at the calibration point, the point will not shrink and disappear, but stay there until you stare at it again.

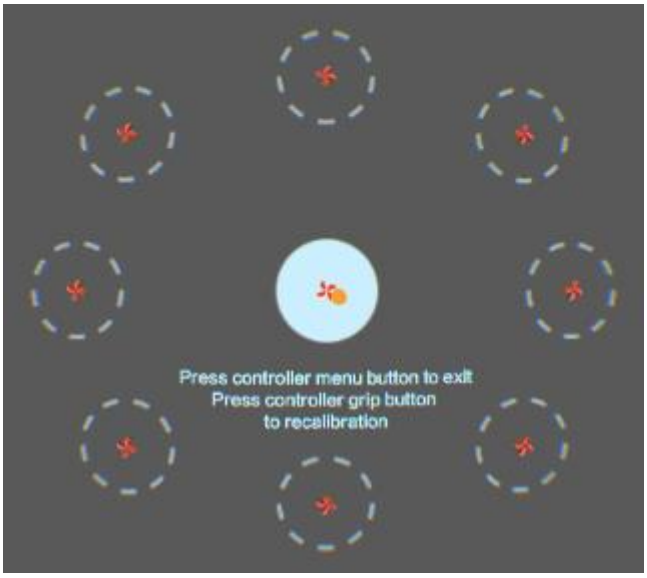
If a calibration point (except for the first one) can't pass during a long time, you can click W on keyboard or grip button on HTC Vive controller to pass forcibly, or you can wait for 15 seconds to pass.

The quantity of the calibration points depends on the calibration mode you choose. If you choose 9-point calibration, 9 calibration points will appear in turns. If you choose 3-point calibration, 3 calibration points will appear in turns. The next scene "Verification" will appear automatically after all calibration points completed.

10.4 Verification

After the calibration is completed, some verification points and your gaze point identifications will be displayed, so that you can determine whether the calibration is accurate.

If not accurate, click the key R on keyboard or grip button on HTC Vive controller to recalibrate until you are satisfied.



10.5 Exit

You can exit the calibration procedure by clicking the ESC on keyboard or menu button on HTC Vive controller. You can also exit the calibration and run the demo in the meantime by clicking G on keyboard.

11 Eye-Tracking Applications

aGlass-vi-1 provides eye-tracking function for HTC Vive. VR content providers will develop VR games or VR applications with eye tracking. When you play these games, or use these applications, your gaze data will be captured for foveated rendering, eye control interaction or eye movement data analysis.

11.1 Foveated Rendering

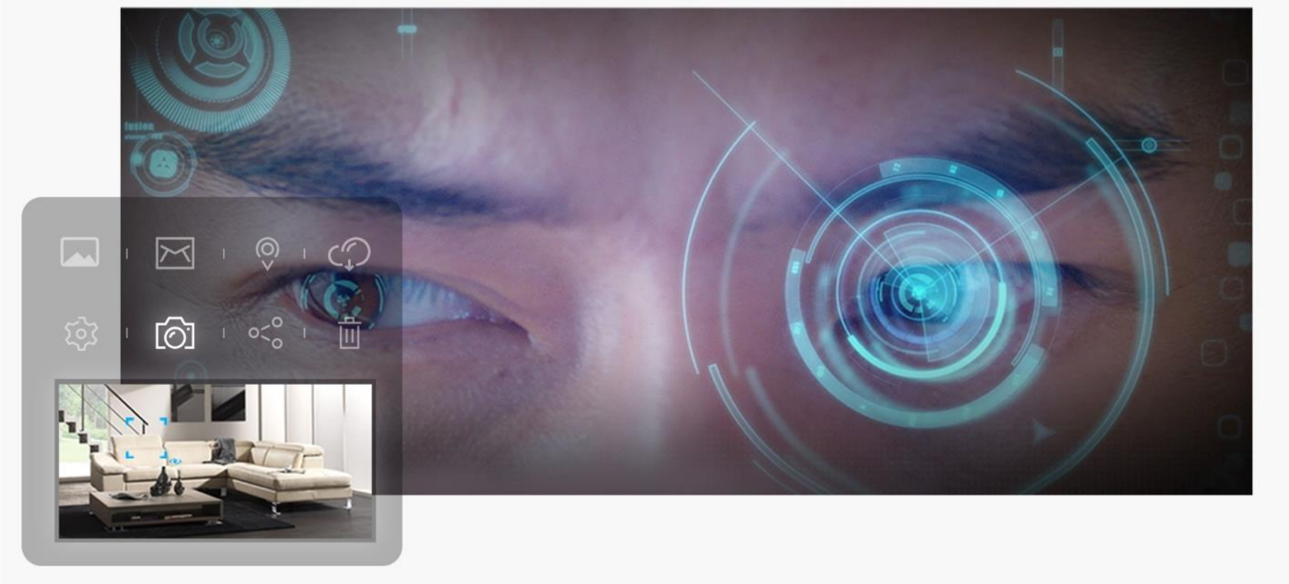
Full high-definition screen plays a key role in VR device. The current rendering method has high demand of hardware and high power consumption. The problem which all VR Hardware enterprises face is that the hardware can't satisfy the requirement of the high-definition rendering. The foveated rendering based on eye-tracking is considered to be the best way to solve the problem.

During the process of imaging in people's eyes, the foveal vision area is clear and with high visual acuity but only cover 1° ~ 2° view, and the peripheral vision field is blurred. With eye-tracking technology, high resolution rendering can be only carried out in gaze points. In this way, images definition can be obtained, GPU efficiency can be enhanced, hardware demanding can be reduced as well. Meanwhile, foveated rendering matches the feature of the human eyes, so it can also alleviate eye fatigue on certain level.

11.2 Eye Control Interaction

In the real world, we preferentially locate targets by rotating eyes, not moving head. The range in which people preferentially observe and track, is called Eye-Only Range (EOR), which is ±30° horizontal and ±12° vertical averagely. In other words, people are used to observe the world by eyes moving not head moving within ±30° horizontal and ±12° vertical.

However, currently, we have to locate targets by head movements based on motion perception of gyroscope, which will aggravate the sense of vertigo and prolong the procedure of targeting. While, integrating eye-tracking technology into VR devices can avoid forcible head movement, recognize users' targets rapidly. Besides, in VR games, players can use their eyes to interact with NPC, switch menu and weapons by gaze, etc.



11.3 Eye Movement Data Analysis

In 21 centuries, data is fortune. VR content platform is predicted to be the next data platform and the final media platform. The quantity and value of the platform has huge potential to promotion. Users' behavior data will become very valuable information fortune for many businesses such as advertising media, content provider and education.

Traditional input methods like mouse and keyboard are not suited for VR. Traditional analysis tools are not suited for VR too. What we can recognize and record are eye-tracking data. So, we can record users' gaze coordinate, trace and time. We can analyze people's behavior by these eye-tracking data.

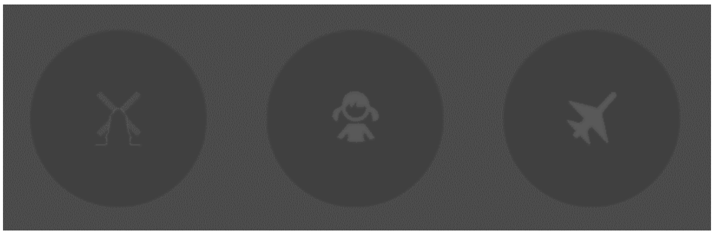
Eye-tracking data will become big data when it is big enough and have big commercial value and research value. The big data can be used in many territories and satisfy many requirements of businesses and research, such as:

- Marketing region: E-commercial based on VR will rise and the consumer behavior analysis will become import marketing research. Enterprises can push accurate contents to consumers based on the analysis data.
- Education region: Eye-tracking in VR can be used to analyze behavior of learners and trainers, and can be used to correct studying and training behavior, such as students' learning interests and attention, athletes' consciousness and ability of cognizance.
- Academics region: Eye-tracking data can be used in spatial cognition and task cognition research in total control immersive VR environment.

11.4 Eye Tacking Demo

If you have completed the calibration in aGlass runtime, you can click “Run Demo” in the right-click menu to experience aGlass eye-tracking in VR applications.

The demo menu is shown first:



Under the demo menu view, you can click 1, 2 or 3 on keyboard to enter the first, second or third demo. You can click ESC on keyboard to back to the demo menu.

The first demo demonstrates the foveated rendering. The center of the green circle is your gaze point. The green circle region is high-resolution rendered; the region between the green circle and blue circle is medium-resolution rendered; the region outside of the blue circle is low-resolution rendered. The GPU’s load is reduced. You won’t feel the resolution of the peripheral region is reduced because of the feature of your eyes.

You can switch the circles indicating foveated rendering region by click D on keyboard.

This demo also demonstrates eye control interactions. When you look at some object in the view, those objects have corresponding reactions, for example, when you observe the door of the cabin, the door will open, and when you observe a pumpkin, the pumpkin will jump.

The scene of the demo is shown below:

The second demo demonstrates some eye-control interactions:

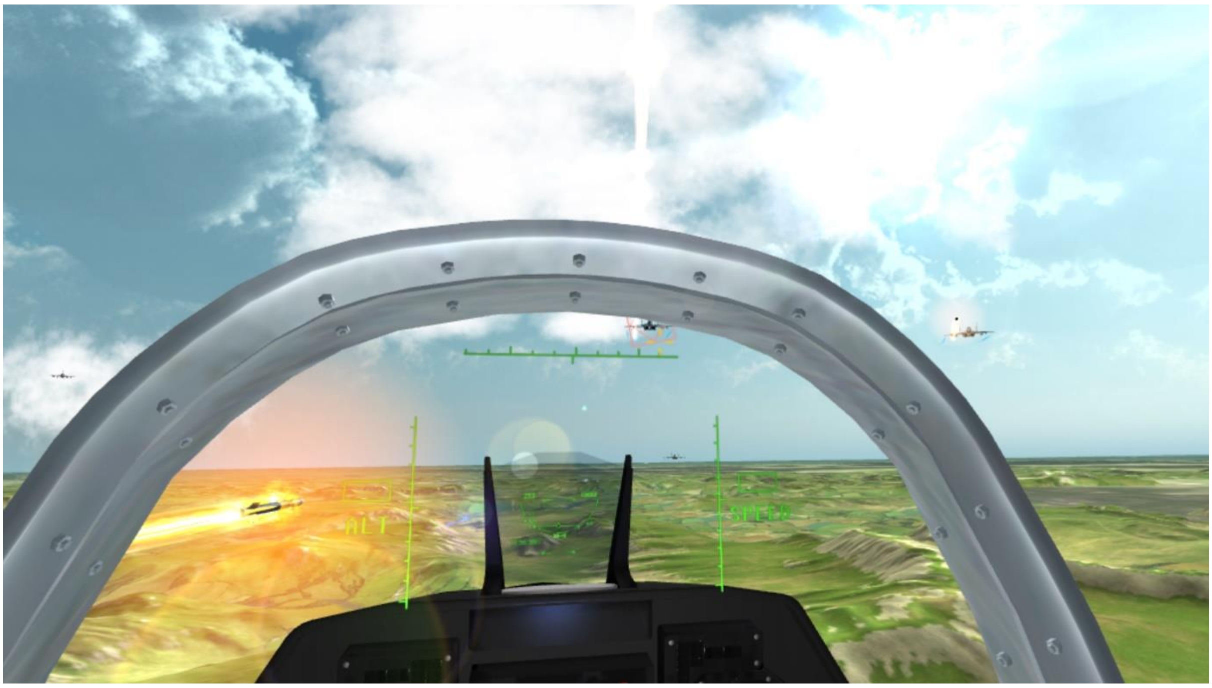
- When you observe the NPC, they will communicate with you by text dialog.
- When you observe the shining circle on the path, you will move to the position of the circle.
- When you observe the goods which the NPC sells, the prices of the goods will display above the goods.

The scene of this demo is shown below:

The third demo demonstrates the gaze aim function in game. When you stare at an enemy plane, the plane will be locked. When you click space on keyboard or trigger the flying rocker, your plane will launch tracked missile aiming the locked enemy plane.

You can click R to restart the game.

The scene of the demo is shown below:



12 Troubleshooting and FAQ

Questions	Answers
Papery users' manual is not detailed enough. Is there operation instructions more detailed?	Users' manual more detailed: Click http://www.aglass.com/user/ Or download from http://www.aglass.com/download/ Developers' manual more detailed: Click http://www.aglass.com/developer/ Or download from http://www.aglass.com/download/ API reference: Click http://www.aglass.com/developer/API Or download from http://www.aglass.com/download/
I can't assemble the module into the HTC Vive HMD, what can I do?	Click http://www.aglass.com/user/, watch the video of module assembly and disassembling, imitate the operations in the video.
The calibration options are all gray and have no effect when I click them, what can I do?	Make sure the HTC Vive is power on. Make sure the aGlass module is connected correctly, and connected with HTC Vive by USB cable.
When calibration start, the computer shows the OpenVR is failed. What can I do?	Make sure the SteamVR is installed. If not, install Stream and SteamVR and check the HTC Vive work correctly under SteamVR.

When calibration start, the computer shows that the USB key is not found, what can I do?	Make sure the USB key is connected correctly, that is, the USB key is plugged in the computer.
A point can't pass when I calibration, what can I do?	You can click W on keyboard or grip button on HTC Vive controller to pass forcibly, or wait for 15 minutes to pass automatically.
I want to take the module out of the HTC Vive, but failed. What can I do?	Click http://www.aglass.com/user/, watch the video of module assembly and disassembling, imitate the operations in the video.
Can I use it wearing glasses?	It's not recommended because it will be difficult putting glasses into HTC Vive. We supply myopic lens of 200°, 400° and 600°. If it's not suited for you, you can order customized lens from our company.
Are there any important matters need attention?	Make sure the HTC Vive power on and connected correctly. Make sure the aGlass module assembly correctly, and the posture is upright not skew. Make sure the nose rest doesn't impact the assembly and doesn't shelter the sensor beneath of the module. Make sure the USB work correctly, avoid bad connection. Avoid any obstacles between eyes and HTC Vive lens. Make sure the Steam and SteamVR is installed. Avoid stepping on the HTC Vive cable.

13 Handing of the Waste Electrical

This product should not be disposed with other household wastes at the end of its working life.

To prevent possible harm to the environment or human health from uncontrolled waste disposal, please separate this from other types of wastes and recycle it responsibly to promote the sustainable reuse of material resources.

Household user should contact either the retailer where they purchased this product or their local government office, for details of where and how they can take this item for environmentally safe recycling.

Business user should contact their supplier and check the terms and conditions of the purchase contract. This product should not be mixed with other commercial wastes disposal.

14 After Service

1) Consultancies: please read this user manual carefully before using this product. For any problem during using it, you can either contact our company or the local retailer, or call our customer service Hot line:400-800-1390
2) Exchange service: within exchange time limit, for any indeliberate error during proper use, making sure the product as well as its accessories and package are all not damaged (if the appearance is damaged, it can only be repaired) you can either have it exchanger for a new one or repaired after the error is tested and examined.
3) Warranty service: within the warranty time limit, for any indeliberate error that occurs during proper use, warranty service is free for no charge (the product has warranty service for free within one year; for any deliberate damage, the warranty service should be paid.)
4) Changed warranty service: within three years counting form one year after the date the product was product was purchased, any error repair will be changed; and user should pay the repair components, freight and labor cost.
5) Any of the below situation is not the warranty service, but we provide changed service.
    a) The warranty date is expired.
    b) The warranty card is altered, or the series number differs from that of the product.
    c) Accidental or deliberate damage is done to the product.
    d) Cannot provide valid warranty card or invoice (other but can prove that it is within the service limit).
    e) Any error damage caused by force majeure such as earthquake, fire, flood, lightning strike etc,.
    f) Deliberate assembling, repair or reform without permission form our company.

15 3rd Party Copyright Statement

HTC Vive is brand of HTC, and all rights belong to HTC.

Steam and SteamVR are brands of Valve, and all rights belong to Valve.

Exhibit E

Exhibit E

EXHIBIT E – SCREENSHOTS OF AGLASS.COM/PRODUCT
(LAST VISITED 16AUGUST2018)

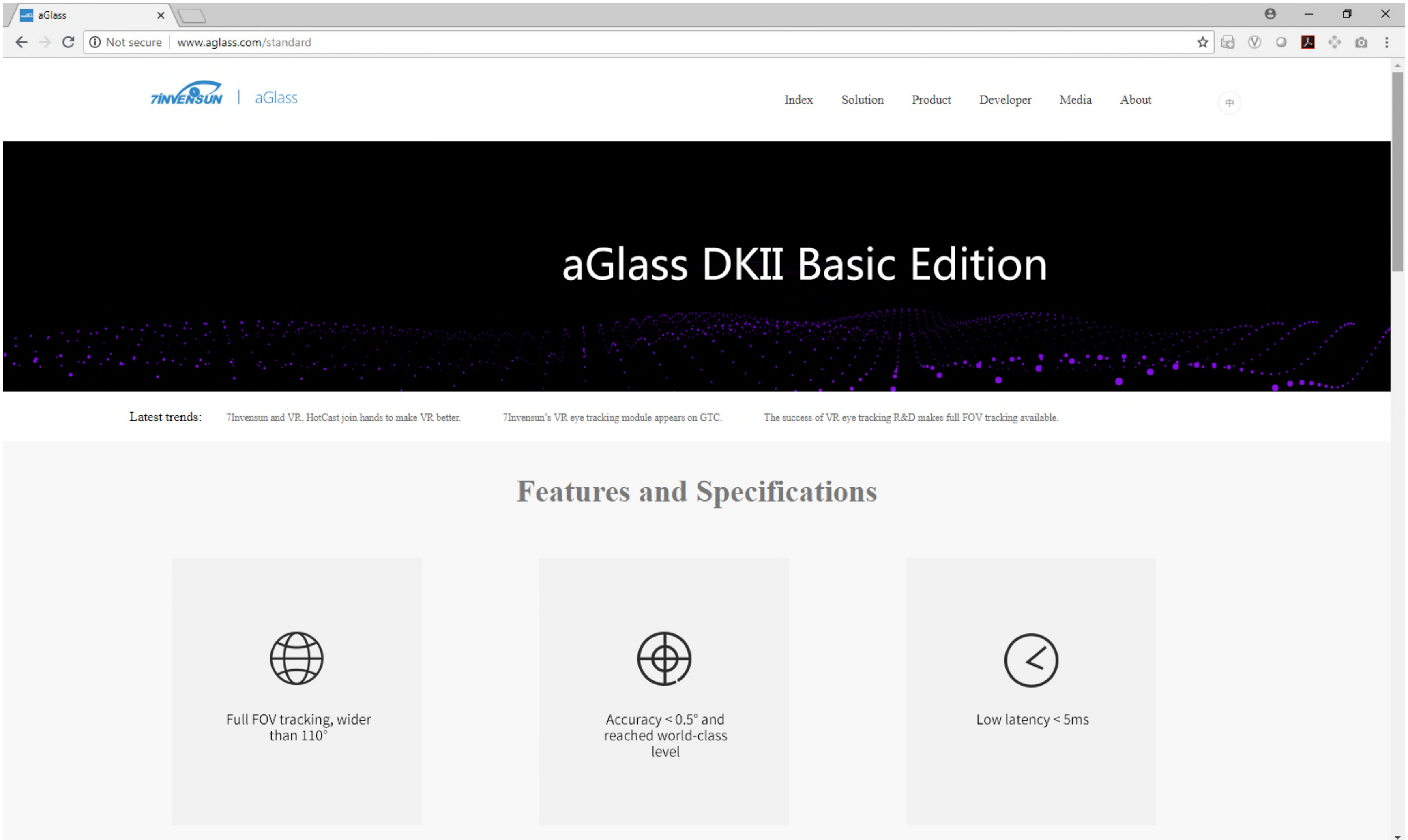


EXHIBIT E – SCREENSHOTS OF AGLASS.COM/PRODUCT
(LAST VISITED 16AUGUST2018)

aGlass

Not secure | www.aglass.com/standard

Add-on product. Plug and play

Support vision lenses. Supply 200, 400 and 600 myopic lenses and can be customized

Supply SDK for Game developers

VR Games and Apps

Super Ninja Hero

"super ninja hero vr" is a VR-FPS game(first-person shooting game) that developed by Wuhan Firegame Co.,Ltd..Variety of scenes with cool fighting, strong cunning enemies and smart boss.Taking up your arms to begin a legend.

The Qiao's Family Compound

17vision's full 3D simulation work. The realistic picture style simulates the architectural culture style of shanxi Qiao's family courtyard. Foveated rendering realized with aGlass.

EXHIBIT E – SCREENSHOTS OF AGLASS.COM/PRODUCT
(LAST VISITED 16AUGUST2018)

aGlass

Not secure | www.aglass.com/standard

VR Games and Apps

Super Ninja Hero

"super ninja hero vr" is a VR-FPS game(first-person shooting game) that developed by Wuhan Firegame Co.,Ltd..Variety of sceneswith cool fighting, strong cunning enemies and smart boss.Taking up your arms to begin a legend.

The Qiao's Family Compound

17vision's full 3D simulation work. The realistic picture style simulates the architectural culture style of shanxi Qiao's family courtyard. Foveated rendering realized with aGlass.

Elevator Maintenance

17vision's elevator maintenance course realized foveated rendering by using aGlass which enhanced the fluency of the scenes.

CODE 51

can fulfill your dream of operating a machine armor. Eye-tracking can make you aim enemy more quickly and fight full of joy.

EXHIBIT E – SCREENSHOTS OF AGLASS.COM/PRODUCT
(LAST VISITED 16AUGUST2018)

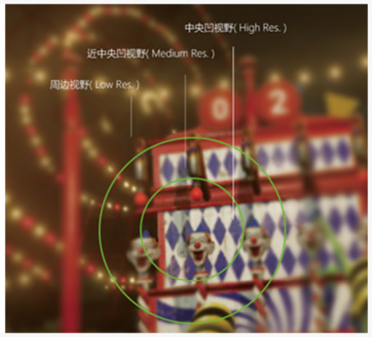
aGlass

Not secure | www.aglass.com/standard

Applications

Foveated Rendering

According to the physiological characteristics of human eyes, HD rendering can be carried out only for the central fovea visual field, while reduces the rendering of the marginal visual field, which can greatly reduce the load of the GPU.



Gaze Based Interaction

In real life, people preferentially turn their heads to control their vision fields and locate targets by rotating their eyes; eye control interaction is more natural and more efficiency in VR.

Developer

Develop aGlass DKII

Technical support Tel

Connect technicist

400-880-1390

EXHIBIT E – SCREENSHOTS OF AGLASS.COM/PRODUCT
(LAST VISITED 16AUGUST2018)

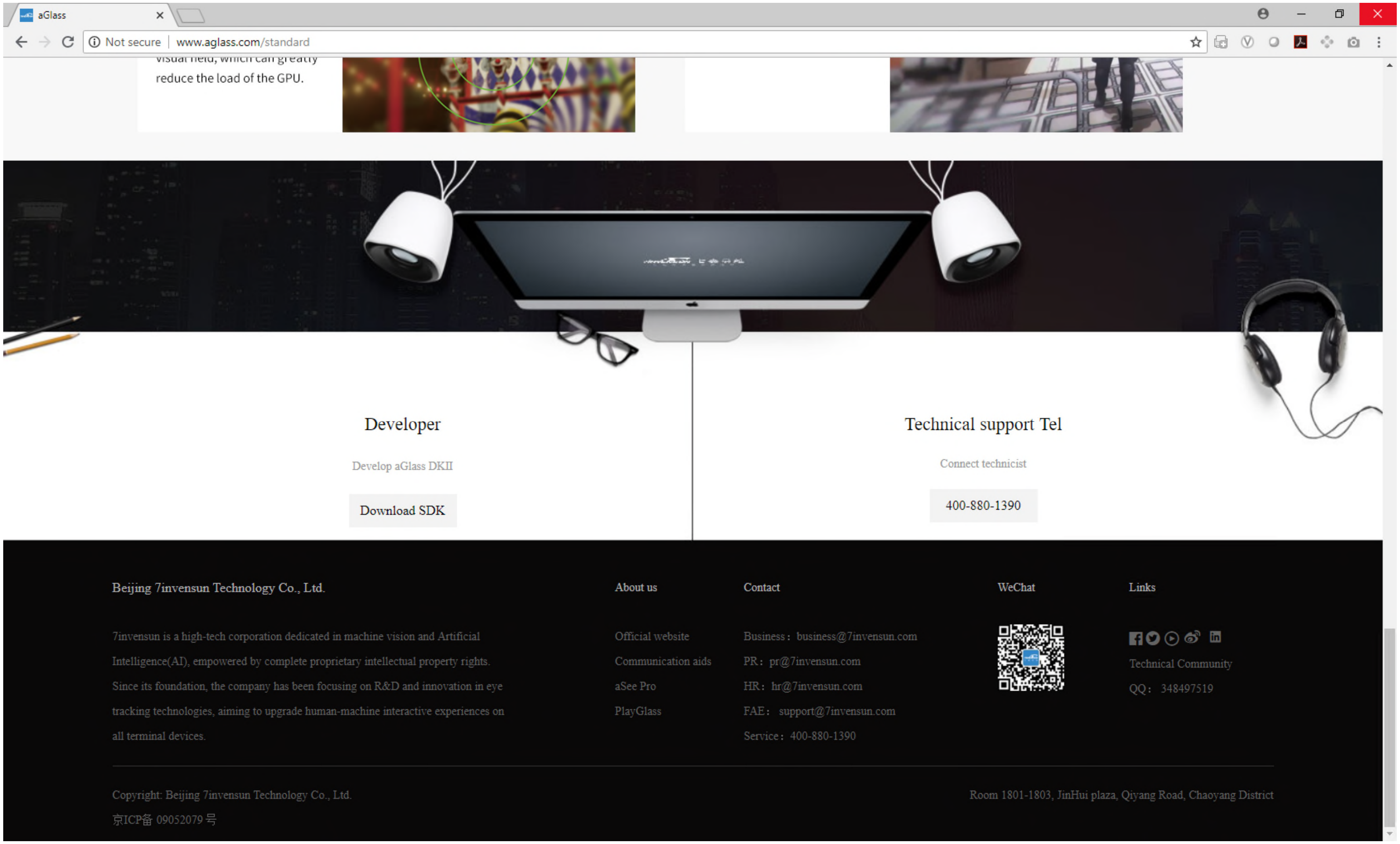


Exhibit F

Exhibit F

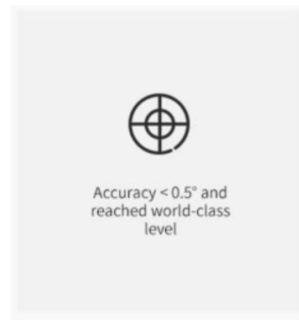
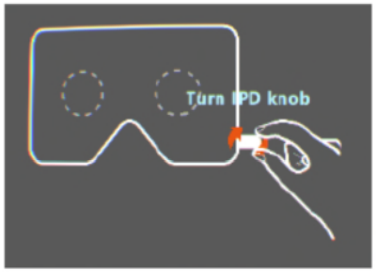
	Claim Language	***aGlass DK II Module***
1	1. A method for eye gaze tracking, comprising the steps of:	The aGlass DK II module is an eye tracking module that performs a method for eye gaze tracking. For example, see Exhibit E (http://www.aglass.com/product), which refers to the aGlass DK II device as an "eye tracking module" having a particular "accuracy": 7Invensun's VR eye tracking module appears on GTC. and 
2	creating a set of reference points in a reference coordinate system;	The aGlass DK II module creates a set of reference points in a reference coordinate system. Specifically, the aGlass DK II module includes multiple infrared LEDs that emit light and create a test pattern in a reference coordinate system. The below image shows an annotated photograph of the aGlass DK II module.

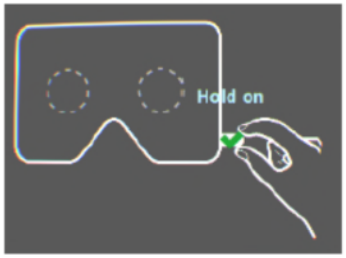
EXHIBIT F - CLAIM CHART
U.S. PATENT NO. 6,659,611

	Claim Language	*aGlass DK II Module*
		 Similarly, the below image shows a screenshot from: https://www.youtube.com/watch?v=eBfWnaEwzRI. The YouTube video shows the DK I product, however, on information and belief, the DK I and DK II are substantially identical with regard to this claim element. The screenshot shows the illuminated infrared LEDs.  Further, the aGlass DK II Users Manual states, "aGlass DK II uses the way of infrared lighting (wavelength 850 nm)." *See* Exhibit C at Page 13 of 15. The LEDs depicted in both images above are infrared lights and the screenshot identifies the LEDs as "Low-power infrared LED."
3	acquiring at least one image of at	The aGlass DK II module acquires at least one image of at least one of a user's corneas,

	Claim Language	***aGlass DK II Module***
	least one of a user's corneas, said image having image aspects in an image coordinate system and including reflections of said reference points;	said image having image aspects in an image coordinate system and including reflections of said reference points. Specifically, an image sensor captures an image of the user's eye, the image having image aspects and including reflections of the reference point.  The claimed image sensor is labeled "Specialized High-speed Eye Tracking Sensor" in the screenshot above. Further, the aGlass DK II module acquires images that include information relating to the user's pupils. *See* Exhibit C at Pages 8-9 of 15 :

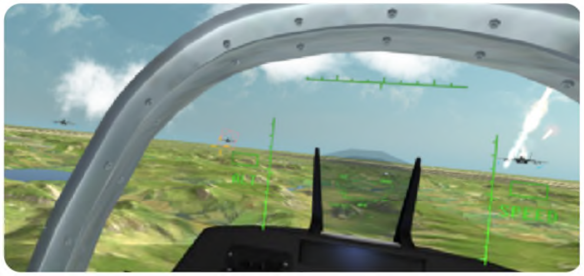
EXHIBIT F - CLAIM CHART
U.S. PATENT NO. 6,659,611

<table>
<tr><th></th><th>Claim Language</th><th>aGlass DK II Module</th></tr>
<tr><td></td><td></td><td>
6.2.1 IPD Adjusting
Put on the Vive HMD. IPD adjust guidance will be seen, like shown below:


Turn the IPD knob according to the instruction in the Vive scene. Stop turning if the following scene displayed:


Hold on to wait the next step.
On information and belief, the aGlass DK II module monitors the interpupillary distance (IPD) by acquiring images that include information relating to a user's pupil.
</td></tr>
<tr><td>4</td><td>defining a mathematical relationship between said reference coordinate system and said image coordinate system;</td><td>The aGlass DK II module defines a mathematical relationship between said reference coordinate system and said image coordinate system.

This step is performed in software, and Tobii does not have access to the relevant</td></tr>
</table>

	Claim Language	*aGlass DK II Module*
		software. On information and belief, it is a fundamental step of image based, infrared eye tracking to mathematically relate an image coordinate system to a reference coordinate system. Tobii believes that it will likely have evidentiary support for this factual contention after a reasonable opportunity for further investigation or discovery.
5	mapping said image aspects from said image coordinate system to said reference coordinate system using said mathematical relationship; and	The aGlass DK II module maps said image aspects from said image coordinate system to said reference coordinate system using said mathematical relationship. This step is performed in software, and Tobii does not have access to the relevant software. On information and belief, it is a fundamental step of image based, infrared eye tracking to use a mathematical relationship between an image coordinate system and a reference coordinate system, to map an acquired image to reference points. Tobii believes that it will likely have evidentiary support for this factual contention after a reasonable opportunity for further investigation or discovery.
6	computing a point of regard from said mapped image aspects.	The aGlass DK II module computes a point of regard from said mapped image aspects. For example, the aGlass User Manual (Exhibit D) at page 8 describes and depicts that a point of regard is generated by the aGlass product for use in a computer system.  The third demo shows the eye-tracking interaction function, through which the user can aim at and select aircrafts when looking at them, and click the space key once to launch missiles.

	Claim Language	***aGlass DK II Module***
		The aGlass User Manual (Exhibit D) relates to the DK I product, however, on information and belief, the DK I and DK II are substantially identical with regard to this claim element.
7	2. The method of claim 1 wherein said reference points include at least one of: a printed pattern around a screen, an unobtrusively interlaced pattern in said screen, a set of controlled light sources around said screen, a set of controlled light sources on said screen, content displayed in said screen, a set of controlled light sources behind said screen	The aGlass DK II module performs the method of claim 1 wherein said reference points include a set of controlled light sources around said screen. Specifically, the aGlass DK II module is to be installed within a HTC Vive headset. See Exhibit C at Page 4 of 15: 3.1 HTC Vive aGlass has to be used after installed in HTC Vive, so please make sure that your HTC Vive is in normal operation, including the base station, headset, link box and controller etc. If your HTC Vive does not work normally, please click https://www.vive.com/us/support/. Accordingly, when the aGlass DK II module is installed in the HTC Vive, the reference points, which are controlled light sources, surround the field of vision for each of the user's eyes. The HTC Vive comprises two separate displays, and the aGlass DK II module contains an eye tracking piece for each display. The reference points of the aGlass DK II module eye pieces are disposed around each HTC Vive display. Accordingly there is "a set of controlled light sources around said screen."
8	3. The method of claim 2 wherein said screen includes at least one of: a computer monitor, a whiteboard, a desktop, a windshield, an advertisement, a television screen.	The aGlass DK II module performs the method of claim 2 wherein said screen is a computer monitor. Specifically, the HTC Vive contains two separate OLED computer displays at a resolution of 1080x1200 each. These computer displays are each small computer monitors.